IMPACTS ON WATER QUALITY IN THE UPPER ELBOW RIVER

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Impacts on Water Quality in the Upper Elbow River

Elbow Falls

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Executive Summary

Recent work has found evidence of significant increases in some key water quality indicators (dissolved phosphorus, coliforms, turbidity) in the Elbow River upstream from Calgary. Consequently, it is very important to identify the reasons for increases in these constituents and take remedial action to protect this drinking water supply.

Accordingly, the City of Calgary and Alberta Environment (AENV) conducted intensive basin-wide sampling of the upper Elbow River and its tributaries from 1999 to 2003, inclusive. The objectives of this sampling were to: (a) describe spatial and temporal trends in the concentration of key water quality indicators, and (b) identify factors that could be contributing to water quality deterioration in the Elbow River. This program included grab sampling of the Elbow River and its major tributaries near their mouths. To ensure all loadings to the river were accounted for in the sampling, daily composite samples for total phosphorus and suspended solids analysis were also collected at five Elbow River sites from above Bragg Creek to Weaselhead Bridge using automated samplers. To determine whether coliforms were from human sources or ungulates, samples were collected for bacterial DNA analysis at sites throughout the basin.

This report presents the results of intensive water quality sampling from 1999 to 2002, inclusive, and bacterial source tracking work in 2003, and compares these findings to previous studies. Included is a statistical analysis of spatial and temporal trends in concentration of key water quality indicators, and, where feasible, a mass flux analysis from Bragg Creek to Weaselhead. The analysis of spatial trends in suspended solids was supplemented by an aerial survey in November 2002, to identify erosion sites and other factors that could contribute to suspended solid concentrations in the Elbow River. Throughout this report, sources other than discrete tributary loadings are described as nonpoint sources. There are no approved point source discharges of wastewater to the Elbow River upstream from Glenmore Reservoir.

Phosphorus is an essential plant nutrient which in excess can cause an increase in the growth of aquatic plants. In turn, aquatic plants can result in low levels of dissolved oxygen through plant respiration at night, impede water flow and affect aesthetics. Results of this study suggest that sources near Calgary between Twin Bridges and Weaselhead Bridge generally contributed most of the total phosphorus (TP) mass entering the Elbow River. Small but significant increasing trends in total dissolved phosphorus (TDP) concentration and total ammonia suggest that sources in this reach are also contributing dissolved nutrients, which will be more biologically-available than TP to stimulate the growth of aquatic plants. Specific sources of phosphorus in this reach cannot be individually identified using the available data, but could include urban runoff from new and old residential developments, agriculture, groundwater, and other nonpoint sources. No evidence of trends in tributary concentration that could account for these increasing trends in TDP in the Elbow River was found. However, TP and TDP median concentrations were higher in tributary streams than in the Elbow River, sometimes well above guidelines and high enough in some streams to have the potential to cause nuisance periphyton growth. Lott Creek contributed the largest mass of TP from tributaries to the Elbow River during 1999 and 2000 when flows were low, and Bragg Creek contributed the greatest TP mass loading among tributaries in 2002, a higher flow year. Although concentrations in tributaries were often high, the mass of TP contributed by tributaries to the Elbow River was much lower than the mass contributed by nonpoint sources, because tributary flows were generally low. In contrast, Lott Creek contributed a greater mass of TDP than nonpoint sources to a lower reach of the Elbow River in 2000.

Nitrogen (N) is another essential nutrient for aquatic plants. Excessive nitrogen can lead to increased growth of aquatic plants; high levels of nitrate can impair drinking water quality, and high levels of ammonia and nitrite may be toxic to aquatic life. Appreciable mass loading of nitrate+nitrite-N occurred in 1999 and 2002 between Twin Bridges and Weaselhead from nonpoint sources close to Calgary and loadings from Lott Creek. Nonpoint sources in this reach could include loadings from urban runoff contributed by storm sewers, atmospheric deposition, agriculture, and contributions from groundwater. A significant increasing trend in nitrate+nitrite concentration occurred at every Elbow River site from just upstream of Bragg Creek to the Weaselhead Bridge, and in several headwater tributaries including the near-pristine Little Elbow River. The reason for these increasing trends in nitrate+nitrite along the Elbow River cannot be determined from the available data. Tributaries between Highway 22 and the Glencoe Golf and Country Club (Glencoe GCC) were major sources of nitrate+nitrite, in particular Pirmez Creek, which contributed a greater mass of nitrate+nitrite each year than any other tributary. Nitrate concentrations were high enough to have the potential to cause nuisance growth of periphyton in Pirmez Creek in some years. However, nitrate+nitrite at all sites was well below Canadian water quality guidelines. Total nitrogen (TN) and total kjeldahl nitrogen (TKN) mass flux generally followed the same pattern as nitrate+nitrite, with a loss of mass along some reaches of the Elbow River during low flow years (1999 and 2000), and some evidence of loading from Lott Creek and from nonpoint sources close to Calgary in 1999. Tributaries contributed a greater mass of TKN and TN to the Elbow River than nonpoint sources during low flow years. Although TKN and TN median concentrations were generally highest in Millburn Creek, Lott Creek contributed the greatest mass of TKN in 1999 and 2000, and Bragg Creek was the greatest tributary source of both variables in 2002, when flows were higher.

Total suspended solids (TSS) is a measure of the total amount of suspended particles such as fine silt and clay, organic matter and small organisms in water. These particles can carry nutrients and toxic contaminants, interfere with water treatment, can be aesthetically undesirable, and kill aquatic life when they settle onto a stream bottom. Sources between Twin Bridges and Weaselhead Bridge contribute the bulk of the TSS in the Elbow River during low to average flows. Some possible sources include the re-suspension of bed material, bank erosion, and storm sewers that release urban runoff. TSS loadings from all Elbow River tributaries were very small each year compared to nonpoint sources along the Elbow River, with only 0.3% of the total mass flux coming from tributaries in 2002. During the high flows in 2002, a large influx of TSS mass occurred between Bragg Creek and Highway 22, more than was contributed by nonpoint sources along any other reach of the Elbow River that year. Bank erosion at various sites and other potential TSS sources in that reach were identified during an aerial survey in November 2002. This large influx of TSS mass probably caused concentrations in 2002 to peak at the Glencoe GCC, and a significant increasing trend in TSS concentration over time was also detected at that site. The mass flux analysis suggests that the area of greatest deposition of TSS occurred just upstream of Twin Bridges in 2000, but more deposition occurred downstream between Twin Bridges and Sarcee Bridge during the higher flows in 2002. These findings suggest that the spatial pattern of TSS loading and deposition changed considerably from year to year depending on river flows and other factors.

Fecal coliforms are found in the intestinal tract of warm-blooded animals, and are a useful indicator of contamination from sewage or manure. *E. coli* is one species of fecal coliform bacteria, and is generally considered the preferred indicator for fecal contamination. The greatest change in *E. coli* counts in the Elbow River occurred each year between the Glencoe GCC and Weaselhead Bridge. *E. coli* counts declined from Highway 22 to the Glencoe GCC in 1999 and 2000, then increased significantly at sites further downstream. *E. coli* counts were generally significantly higher at Twin Bridges and Weaselhead Bridge than at most upstream sites, including the site at the Glencoe GCC. Fecal coliforms have increased significantly over time (1979-2002) at the Twin Bridges site alone. Except for Lott Creek, Elbow River tributaries had higher *E. coli* and fecal coliform counts than the mainstem sites in low to average flow years (1999 and 2000). Among tributary sites, both *E. coli* and fecal coliforms were consistently lowest in Lott Creek, and highest in either Pirmez or Millburn Creeks. Fecal coliform counts in Pirmez Creek and Millburn Creek often exceeded the guidelines for irrigation and contact recreation, indicating that water quality for these uses was impaired in both streams. Since no trend in fecal coliform counts was found in the Elbow River at Glencoe GCC, immediately downstream from Pirmez, Millburn, and Springbank Creeks, no evidence was found that activities on those tributaries would account for the increasing trend in fecal coliform counts in the Elbow River at

Twin Bridges. Similarly no evidence was found that human sewage could account for this trend. Nonpoint sources such as runoff from residential developments and agriculture, or contributions from groundwater could account for increasing fecal coliform counts in the Elbow River at Twin Bridges. As with other variables in this reach it is not possible to determine the relative importance of various potential sources of coliforms from results available to date.

In the 2003 bacterial tracking study, DNA markers from ruminant animals were found in samples at each location in the Elbow River basin on at least one sampling date, except for sites on Lott Creek, the headwaters of Pirmez Creek, Weaselhead Bridge, and the headwaters of Millburn Creek. These results confirm that ruminant animals are present upstream from all sampling locations where such markers were found, even in the headwaters of the Elbow River at Cobble Flats. A wide range of wild and domesticated animals that occur in this basin are ruminants, including cattle, bison, sheep, elk, and deer. No human markers were found at any sampling site, although this marker was found in a raw sewage sample. This implies that there was little or no movement of bacteria from human sewage to these water bodies during the sampling period. Of the human pathogens for which samples were tested in the bacterial source tracking study, there was only one positive result for *Salmonella* at one site, on one date. Neither *E. coli* 0157:H7 nor *Campylobacter* were detected.

Results of this study did not provide consistent evidence of impacts on surface water quality in the Elbow River that might be attributed to sources in the Hamlet of Bragg Creek. In 1999 before the spring flood, nonpoint sources contributed 454 kg TP to the Elbow River between the Hamlet of Bragg Creek and Highway 22, however there was no increase in TP mass between these sites in 2000. *E. coli* counts increased each year between the Hamlet of Bragg Creek and Highway 22, but counts at these sites were only significantly different in 2000.

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Introduction

The Elbow River is a relatively small river that provides water to meet a variety of needs. These needs include consumptive (municipal and agricultural supply) and non-consumptive uses, such as recreational activities and habitat for fish and wildlife. Most importantly, the upper Elbow River is a source for drinking water for the City of Calgary. The upper Elbow River watershed is here defined as the basin upstream of Glenmore Reservoir.

The City of Calgary has used the Elbow River as a source of drinking water since 1909. Until 1932, a constructed gravity system and direct feed from the intake west of Twin Bridges was used to direct water to the City. In 1932, the river was impounded and the Glenmore Water Treatment Plant, which draws water from the Glenmore Reservoir, was built. Until 1972 and the opening of the Bearspaw Water Treatment Plant, the Elbow River supplied the entire City. Since then it has served about one-half the population of Calgary, which currently stands at around 950,000 or approximately one-sixth of Alberta's population.

The Elbow River Water Quality Steering Committee and Task Force (1993) identified the Elbow River watershed as a very important resource, and recommended a definite need to recognize growing land use and development pressures along the entire river system, and to undertake measures to provide protection, including an improved and integrated water quality monitoring program. In addition, the Upper Elbow River Instream Objectives Working Group, established in 1997, agreed that because of its unique nature the upper Elbow requires instream objectives designed to protect the aquatic and riparian ecosystems, and preserve current and future human use of water in the basin. They concluded that, while quantity and quality of water in the upper Elbow was good when compared to requirements for the aquatic ecosystem and human uses, some deterioration in water quality was occurring.

Over the last 20 years, numerous studies have examined water quality in both the Glenmore Reservoir and the upper Elbow River watershed (Hudson, 1983; Hargesheimer and Lewis, 1985, 1988; MMM, 1985; JNMackenzie Engineering, 1992; Beers and Sosiak, 1993; Dixon et al., 1993; Lewis and Seidner, 1993; Dixon, 1994; Watson et al., 1996; Sosiak, 1999; Watson et al., 2001; Zaitlin et al., 2003). The Elbow River Watershed Study by Marshall Macklin and Monaghan (MMM, 1985) identified land use activities in the watershed that posed a potential risk to the water supply. The study found that water quality of the Elbow River and Glenmore Reservoir, although acceptable, was at risk because of continued urbanization and development in the Elbow River watershed. Urban influences, especially stormwater runoff from the City of Calgary to the river and reservoir, were examined in studies by JNMackenzie (1992) and Dixon (1994). Lewis and Seidner (1993) found an increasing trend in disinfectant demand at the Glenmore Water Treatment Plant, which resulted in an increase in the production of disinfection by-products. Algal blooms of increasing intensity have been observed in recent years in the reservoir (Dixon et al., 1993; Watson et al., 1996, 2001), and these blooms have led to consumer complaints about taste and odour in the treated water. Two major sources which could affect water quality in the Elbow River watershed are: (1) nonpoint source runoff from agriculture, recreation, and residential developments in the upper watershed; and (2) urban runoff from Calgary conveyed to the Elbow River and Glenmore Reservoir primarily by the storm sewer system (EMA, 1993). The main issues relative to water quality that were identified included: taste and odour, disinfection by-products, microbial pathogens, and turbidity.

Increasing trends in dissolved phosphorus, total suspended solids, turbidity, and coliforms in the Elbow River upstream from Glenmore Reservoir indicate that water quality has deteriorated in recent years (Sosiak, 1999). While the taste-and-odour aesthetic guideline has not always been met, treated water from the Glenmore Water Treatment Plant has otherwise met the guidelines for Canadian Drinking Water Quality (The City of Calgary Waterworks). Furthermore, most water quality variables in the Elbow River remain well below surface water quality guidelines upstream from Glenmore Reservoir. However, it is important to identify factors contributing to increasing trends in these variables and take action before significant deterioration of this important water supply occurs. It is very difficult to restore a highly productive water body to a natural state (Marsden, 1989).

The objectives of an intensive sampling program carried out by The City of Calgary and Alberta Environment (AENV) from 1999 to 2002, inclusive, were: (a) to describe spatial and temporal trends in the concentration of key water quality indicators, and (b) identify factors that could be contributing to water quality deterioration in the Elbow River. The results of this sampling program are presented in this report. Included also are the results of a bacterial source tracking study that was carried out in 2003. A statistical analysis of spatial and temporal trends in concentration of key chemical indicators and coliform counts, and where feasible a mass flux analysis from Bragg Creek to Weaselhead are included in this report. An aerial survey was conducted in November 2002, to identify erosion sites and other factors that could contribute to suspended solid concentrations in the Elbow River.

Description of Study Area

The Elbow River originates in the front range of the Rocky Mountains of southern Alberta approximately 95 km west of the City of Calgary (Figure 1). It drains a large basin covering 1220 km^2. From its source at Elbow Lake to its confluence with the Bow River within the City of Calgary the watershed extends through portions of four ecoregions: alpine, sub-alpine, boreal foothills, and aspen parkland (Mitchell and Prepas, 1990). In addition, the river basin extends through four local jurisdictions: Kananaskis Country Improvement District No. 5, Rockyview Municipal District No. 44, Tsuu T'ina First Nation, and The City of Calgary. The Elbow River generally flows in a single channel with a pool and riffle pattern, however, upper canyon reaches are fast flowing and braiding occurs extensively, especially at the mountain front and in the mid-reaches (EMA, 1993).

The majority of the Elbow River watershed (63%) lies within Kananaskis Country, which is principally zoned Forest Reserve. Approximately 264 km^2 or 22% of the watershed lies within the M.D of Rockyview No. 44. Eighty percent of this area is agricultural and approximately 16% is residential. Agriculture consists mostly of cattle ranching operations on large, open tracts of land, rather than crop production. Aerial surveys on two dates in 2003 counted from 1483 to 1958 cattle in the upper Elbow (C. Ryan, 2004, University of Calgary, personal communication)

Most of the residential development in the upper Elbow watershed is on large lots ($\geq$ 2 acres), but the number of smaller-lot, cluster-type subdivisions has increased in recent years (Elbow River Water Quality Steering Committee and Task Force, 1993). Population in the upper Elbow basin increased by 45% from 1981 to 1996, and is expected to increase by a further 67% to 2021 (medium growth projection; Hydroconsult, 2002). Thirteen percent of the Elbow watershed lies within Tsuu T'ina First Nation Lands, and the remaining 2% within the City of Calgary.

Reaches

Headwaters to Bragg Creek

In this reach, the Elbow River originates in the front range of the Rocky Mountains in southern Alberta and flows from Elbow Lake through Kananaskis Country to just above the Hamlet of Bragg Creek. Dominant land uses include recreation activity (campgrounds, equestrian, Off-Highway Vehicle (OHV) in the McLean Creek sub-watershed, hiking, mountain biking, day-use), resource extraction (logging, gas exploration and development), agricultural (domestic grazing leases), and some limited country residential development between Kananaskis Country and the Hamlet of Bragg Creek.

Tributaries to this reach include: Little Elbow River, Ford Creek, Quirk Creek, Powderface Creek, Prairie Creek, Canyon Creek, Silvester Creek, Ranger Creek, McLean Creek and Iron Creek.

This reach of the river is approximately 62 kilometres in length and drains an area of 725 km^2, or 58% of the upper Elbow watershed.

Bragg Creek to Highway 22 Bridge

This reach of the Elbow River extends from just above the Hamlet of Bragg Creek to the Highway 22 (Clem Gardner) Bridge river crossing. Dominant land uses in this reach include residential development (Hamlet of Bragg Creek, Redwood Meadows, a few country residential estates), agriculture (livestock grazing and forage crop production primarily in the lower reach and the Bragg Creek sub-watershed), and recreation (Wintergreen golf course and ski-hill (since closed), hiking, biking, snowmobile use, cross country skiing in the west Bragg Creek recreational area). Much of the reach extends through the north-west corner of the Tsuu T'ina First Nation lands. This section is largely forested and undeveloped, except for the golf course and housing development at Redwood Meadows.

The Hamlet of Bragg Creek has a population of 500, a number that increases to approximately 2,000 when considering the surrounding area (M.D. Rockyview, April 2000 census). There is no communal water or wastewater system; water needs are managed by individual wells or small co-ops. Wastewater is handled individually by septic or sewage pump-out systems. The population of Redwood Meadows in 2001 was

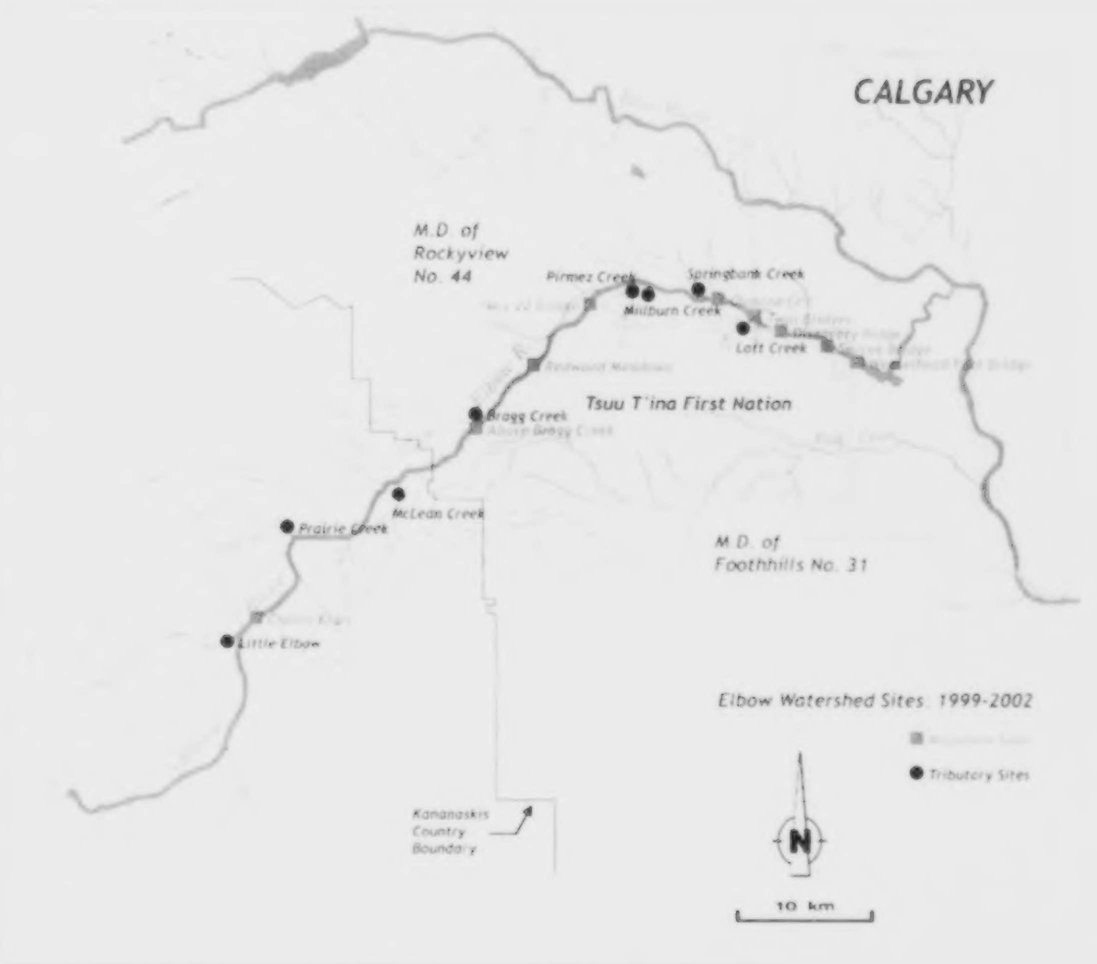
CALGARY
M.D. of Rockyview No. 44
Pirmez Creek
Springbank Creek
Millburn Creek
Lott Creek
Redwood Meadows
Tsuu T'ina First Nation
Bragg Creek
Above Bragg Creek
McLean Creek
Prairie Creek
Little Elbow
M.D. of Foothills No. 31
Elbow Watershed Sites: 1999-2002
Tributary Sites
Kananaskis Country Boundary
N
10 km

Figure 1. The Elbow River showing mainstem and tributary sampling site locations: 1999-2002.

1,141 (Alberta Municipal Affairs, 2001 Official Population List). Water and wastewater are communally serviced. A water treatment plant provides potable water to the community, and wastewater is pumped east from the townsite to a lift station and then to a sewage lagoon system situated between the mid-reach of Millburn Creek and the headwater of the Lott Creek sub-watershed. Sewage is not discharged from this system to either of these creeks.

Tributaries to this reach include: Bragg Creek and Lyon Creek. These tributaries drain lands to the north of the river. Bragg Creek drains primarily agricultural and country residential land uses and Lyon Creek drains the Wintergreen golf course and ski hill and surrounding lands. Wastewater is handled individually by septic or sewage pump-out systems.

This reach of the river is approximately 14 kilometres in length and drains a cumulative area of 886 km^2, or 73% of the upper Elbow watershed.

Highway 22 Bridge to Twin Bridges

This reach extends from downstream of the Highway 22 Bridge crossing of the Elbow River to downstream of the Highway 8 Bridge, an area commonly referred to as Twin Bridges. The predominant land use in this reach is agricultural, and consists of cattle grazing, pasture land, and forage crop production. Of secondary, but increasing, importance is country residential development, both large-lot and smaller-lot, cluster-type subdivisions. Existing and recent residential estate developments along the mainstem include Elbow River Estates, Stonepine, and the Riverside phase of the Elbow Valley development. Wastewater from the Elbow Valley and Stonepine developments is serviced by the City of Calgary Wastewater system.

Tributaries to this reach include Pirmez Creek, Millburn Creek, Springbank Creek, and Cullen Creek. Pirmez Creek and Millburn Creek drain primarily agricultural lands: cattle grazing, pasture and forage crops. Springbank Creek drains a diverse assemblage of land uses, including agricultural, country residential, and commercial/institutional (Springbank Park for all Seasons recreational facility, and elementary, middle and secondary schools). The recreational facility and schools are serviced via a wastewater collection system to lagoons located adjacent to Springbank Creek. Land use in the intermittent Cullen Creek drainage is both agricultural and country residential.

This reach of the river is approximately 19 kilometres in length and drains a cumulative area of 1,152 km^2, or 94% of the upper Elbow watershed.

Twin Bridges to Weaselhead Bridge

This river reach extends from below the Highway 8 bridge crossing of the Elbow River to the pedestrian bridge in the Weaselhead Natural Area of North Glenmore Park in the City of Calgary. The predominant land use in this reach includes both country and urban residential development. Pinebrook Estates (residential/golf course) is situated north of the river in the western section of the reach, and the Elbow Valley subdivision, a 700-dwelling estate community built in the 1990s, is located in the Lott Creek sub-watershed adjacent to the Elbow Springs golf course. A much higher intensity, urban residential development, Discovery Ridge, has been recently built north of the river in the lower portion of the reach. The lower section of this reach flows through Tsuu T'ina First Nation lands, previously the Sarcee Barracks of the Canadian Forces Base-Calgary, and then through the Weaselhead. The City of Calgary Wastewater system services sewage from residential developments in this reach. Stormwater from urban residential, commercial, and parkland in the City of Calgary drains to the Elbow River in this lower section. Two direct discharge storm outfalls and two stormwater retention ponds discharge to the river between Twin Bridges and Weaselhead. The two direct discharge outfalls are G-19, situated between Sarcee Bridge and Weaselhead Bridge, and G-20, located upstream between Discovery Ridge and Sarcee Bridge. The retention ponds are located at 69th St. S.W and Discovery Ridge.

Tributaries to this reach include only Lott Creek, and a major side channel of the Elbow River, which drains an area north and west of Twin Bridges and empties to the mainstem downstream of Twin Bridges. In the Lott Creek sub-watershed, the primary land use is residential with development of the Elbow Valley subdivision. Trout Springs fish farm and a recreational-vehicle park are also located in this drainage. Trout Springs is situated directly on a channel of Lott Creek. The north channel of the Elbow River drains Pinebrook Estates and a dairy operation of approximately 150 head.

This reach of the river is 8 km long, draining a cumulative area of 1,211 km^2, or 99% of the upper watershed.

Methods

Flow

Tributary flows were measured on sampling days by measuring cross-sectional area of the stream (average depth by width) multiplied by stream velocity (using a stream velocity meter). These discrete measurements were used by AENV, along with data from a long-term flow gauging station on Jumping Pound Creek at Cox Hill (WSC Station 05BH013) to estimate daily tributary flows on all the sampling days when automated samplers were active. Similarly, flow data from long-term gauging stations on the Elbow River at Bragg Creek (WSC Station 05BJ004) and at Sarcee Bridge (AENV Station 05BJ010), along with contributing watershed area to each station, were used to estimate flows during sampling periods at each Elbow River station.

Elbow River inflows to the Glenmore Reservoir (Station 05BJ010) are based on a stage-volume relationship developed for the Glenmore Reservoir and Dam, calculated from metered treatment plant withdrawals, reservoir levels, and dam discharges (The City of Calgary Waterworks, unpublished).

Sampling and Analysis

Mainstem and tributary sites were sampled from March to September, 1999 to 2002, by AENV and The City of Calgary field personnel, usually on a bi-weekly or monthly basis (sites in Figure 1 and Table 1). During each sampling visit, water temperature, dissolved oxygen, and conductivity were measured in the field. Additionally, grab samples were taken for pH, total organic carbon, the various forms of phosphorus and nitrogen, total suspended solids (as nonfilterable residue), and coliform bacteria. Most sampling was conducted during the open water season because previous work indicated this was the period of greatest contaminant loading to the Elbow River and its tributaries. To better sample during periods of peak loading, additional daily composite samples were collected during the anticipated period of peak snowmelt and river flow at key Elbow River sites.

Composite samples for TP and TSS analysis were collected on alternate days every two hours by AENV using automated samplers (ISCO 6700) during April 7 to July 8, 1999, May 1 to August 1, 2000, and April 15 to August 1, 2002. Automated samplers were installed in the Elbow River just upstream of the Hamlet of Bragg Creek, at Highway 22 Bridge, at the Glencoe Golf and Country Club (Glencoe GCC), at Twin Bridges, and at Weaselhead Bridge. Sampler intakes were anchored mid water column, several metres from the bank in the main river flow.

To respond to concerns about whether the historic AENV sampling site on Pirmez Creek near the mouth (site AB05BJ0190) was truly representative of concentrations and flows entering the Elbow River, an additional site 40-50 m from the mouth of the creek (site AB05BJ0620; at mouth) was sampled May 1 to August 1, 2000. This additional site was within the Elbow River flood plain and flows and concentrations at the site appear to have been affected by the Elbow River. Median flow and concentrations at these two Pirmez Creek sites are shown in Table 2. All constituents except TSS were lower in concentration closer to the mouth of Pirmez Creek and more typical of the mainstem Elbow River. However, flows were nearly three times higher at the site closer to the mouth. This suggests that this site was affected by Elbow River water and is not representative of conditions in Pirmez Creek. Consequently all sampling in subsequent years, and all analysis used the historic sampling site (site AB05BJ0190).

For AENV samples, Maxxam Analytics Inc. performed all physical and chemical analyses, and the Provincial Health Laboratory for Southern Alberta provided all coliform counts. For the City of Calgary, all physical, chemical, and microbiological analyses were conducted by Laboratory Services, The City of Calgary Waterworks and Wastewater. All laboratories are accredited facilities. Both AENV and the City of Calgary tested for all variables, except total coliforms, which were analyzed only by the City

Table 1. GPS coordinates for Elbow River mainstem and tributary sample sites.

Site	Latitude	Longitude	UTM Coordinates
Mainstem			
Elbow River above Cobble Flats	50° 48' 18.7" N	114° 50' 08.9" W	11U 0652487E 5630395N
Elbow River above Bragg Creek	50° 56' 36.6" N	114° 34' 51.8" W	11U 0669932E 5646330N
Elbow River at Redwood Meadows	50° 59' 24.8" N	114° 30' 34.2" W	11U 0674782E 5651689N
Elbow River at Hwy 22 Bridge	51° 02' 00.2" N	114° 27' 56.4" W	11U 0677694E 5656594N
Elbow River at the Glencoe GCC	51° 01' 38.9" N	114° 17' 33.6" W	11U 0689846E 5656368N
Elbow River at Twin Bridges	51° 00' 48.9" N	114° 14' 14.3" W	11U 0693785E 5654968N
Elbow River at Discovery Ridge	51° 00' 29.4" N	114° 12' 03.1" W	11U 0696364E 5654463N
Elbow River at Sarcee Bridge	50° 59' 43.2" N	114° 09' 54.7" W	11U 0698919E 5653133N
Elbow River at Weaselhead Bridge	50° 59' 31.1" N	114° 08' 51.7" W	11U 0700163E 5652804N
Tributaries			
Little Elbow River (at the bridge)	50° 47' 28.2" N	114° 51' 28.2" W	11U 0650982E 5628789N
Prairie Creek (at Hwy 66)	50° 52' 00.9" N	114° 47' 20.3" W	11U 0655583E 5637354N
McLean Creek (at Hwy 66)	50° 54' 08.2" N	114° 40' 14.5" W	11U 0663779E 5641543N
Bragg Creek (near the mouth)	50° 56' 49.4" N	114° 34' 40.7" W	11U 0670137E 5646730N
Pirmez Creek (near the mouth)	51° 02' 29.5" N	114° 23' 57.4" W	11U 0682316E 5657661N
Millburn Creek (near the mouth)	51° 02' 13.8" N	114° 23' 08.1" W	11U 0683293E 5657211N
Springbank Creek (near the mouth)	51° 02' 06.9" N	114° 19' 12.5" W	11U 0687889E 5657163N
Lott Creek (near the mouth)	51° 00' 31.5" N	114° 14' 11.9" W	11U 0693852E 5654433N

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Pirmez Creek near the mouth	0.393	7.59	31	110	0.258	0.016	0.009	0.005	0.14	0.355	1.7
Pirmez Creek at the mouth	1.03	11.5	13	23	0.128	0.007	0.002	0.005	0.11	0.281	2.7

[a] Variable abbreviations: Q (flow), Temp (water temperature), *E. coli* (*Escherichia coli*), F. coli (fecal coliforms), NO_2+NO_3 (nitrate+nitrite as N), TP (total phosphorus), TDP (total dissolved phosphorus), NH_3 (total ammonia as N), TKN (total kjeldahl nitrogen), TN (total nitrogen) TSS (total suspended solids, as nonfilterable residue).

bacterial source tracking study, and five major tributaries (Bragg, Pirmez, Millburn, Springbank, and Lott Creek) were sampled above and below the main agricultural areas (Figure 1, Table 1). None of these headwater sites are completely pristine, and all except for Lott Creek have upstream farms with livestock or grazing allotments in the Forest Reserve. There was no flow at the upstream sites on Lott Creek, Millburn Creek, and Springbank Creek on some sampling trips, and accordingly no sample was collected. A composite sample of raw sewage collected by a commercial hauler at many residences and an animal hospital in the upper Elbow River basin was also tested for *Bacteroides* DNA.

Statistical Analysis

To permit numerical analysis, all water quality values less than detection limits were replaced by values one-half the detection limit. Data were then compared to the Alberta Surface Water Quality Guidelines (ASWQG; AENV, 1999) and the Canadian Environmental Quality Guidelines (CEQG; CCME, 2003).

Differences in median concentration of water quality variables among Elbow River sites and tributary sites in individual years were tested using the non-parametric Kruskal-Wallis test (one-way analysis of variance of ranks; SPSS, 2000). Where significant differences were found, the Tukey test was employed to distinguish among-site differences. Hypothesis rejection was performed at the $P=0.05$ level of probability.

Trend Analysis

To determine where deteriorating water quality has occurred in the Elbow basin, sites with at least four years of data ($n>1$ each year) for each variable were tested for monotonic trends, which indicate gradual increasing or decreasing concentration. Ward et al. (1990) note that at least four years of water quality data are required to detect a trend, but such short time series must be interpreted with caution. Variables were first tested with the Kruskal-Wallis test for seasonality. Variables exhibiting significant seasonality were tested for monotonic trends using the Seasonal Kendall Test, with (SKWC) or without (SKWOC) correction for significant serial correlation, using procedures in the computer program WQHYDRO (Aroner, 2000). Data that did not display significant seasonal variation were tested for monotonic trends using the Mann-Kendall test. As recommended by Ward et al. (1990), a 0.10 level of statistical significance was used to assess the results of all trend tests.

Mass Flux

The mass flux of key chemical variables was estimated for sites sampled intensively from Bragg Creek to Weaselhead Bridge, where daily flow estimates were available. Mass flux calculations estimate the total mass of material moving past a site during the period of sampling. These estimates provide a better indication of water quality impacts on the receiving water than comparisons of concentration alone.

For each site, the mass flux of each variable was estimated by six different methods using the computer program FLUX 4.5 (Walker, 1996). The method that produced the lowest coefficient of variation was selected for further analysis in each case. Different methods were sometimes selected for different variables because these methods varied in their accuracy depending on the

Table 1. GPS coordinates for Elbow River mainstem and tributary sample sites.

Site	Latitude	Longitude	UTM Coordinates
Mainstem			
Elbow River above Cobble Flats	50° 48′ 18.7″ N	114° 50′ 08.9″ W	11U 0652487E 5630395N
Elbow River above Bragg Creek	50° 56′ 36.6″ N	114° 34′ 51.8″ W	11U 0669932E 5646330N
Elbow River at Redwood Meadows	50° 59′ 24.8″ N	114° 30′ 34.2″ W	11U 0674782E 5651689N
Elbow River at Hwy 22 Bridge	51° 02′ 00.2″ N	114° 27′ 56.4″ W	11U 0677694E 5656594N
Elbow River at the Glencoe GCC	51° 01′ 38.9″ N	114° 17′ 33.6″ W	11U 0689846E 5656368N
Elbow River at Twin Bridges	51° 00′ 48.9″ N	114° 14′ 14.3″ W	11U 0693785E 5654968N
Elbow River at Discovery Ridge	51° 00′ 29.4″ N	114° 12′ 03.1″ W	11U 0696364E 5654463N
Elbow River at Sarcee Bridge	50° 59′ 43.2″ N	114° 09′ 54.7″ W	11U 0698919E 5653133N
Elbow River at Weaselhead Bridge	50° 59′ 31.1″ N	114° 08′ 51.7″ W	11U 0700163E 5652804N
Tributaries			
Little Elbow River (at the bridge)	50° 47′ 28.2″ N	114° 51′ 28.2″ W	11U 0650982E 5628789N
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The net loading of nutrients and TSS to each reach (i.e., between sampling sites) was estimated by subtracting mass flux at the upstream end of the reach from mass flux at the downstream end. To estimate nonpoint source mass loading directly to various reaches, mass from tributaries was subtracted from Elbow River loading estimates. Only estimates with a coefficient of variation < 0.2 were used for mass flux analysis, as recommended by Walker (1996).

Results and Discussion

Streamflow

Mainstem Flows

Elbow River mainstem flows varied widely between years of this study, both in total discharge and timing of peak flows (Table 3, Figure 2). The 25-year average for Elbow River flows above Glenmore Reservoir have an estimated total annual volume 256,166,695 m^3, and an average peak discharge of 31.4 m^3/s occurring on June 7 of a typical year.

In 1999, the upper Elbow River flow regime was of normal annual volume, with a high but delayed spring peak discharge. Annual volume discharge was 254,080,032 m^3 or 99% of normal in 1999. However, the runoff peak was considerably higher than average and occurred up to a month later than the average date. In 1999, two peaks were observed for the spring runoff: 46.1 m^3/s on July 3, a discharge peak 147% of normal, and a second peak of 53.8 m^3/s on July 16, a discharge 171% of normal.

In 2000, the year was characterized as a low-flow/low-peak discharge regime. Total annual volume was estimated as 156,936,421 m^3, or 61% of normal, and while the peak discharge demonstrated typical timing, occurring on June 9, it was considerably below average at 18.6 m^3/s or 59% of normal. Other runoff events occurred both early in the season, with a small peak of 8.5 m^3/s on March 28, and a late-summer peak discharge of 10.8 m^3/s on September 2.

In 2001, Elbow River discharge was classified as low-volume/high-peak. Total annual volume was estimated as 183,2451,118 m^3 or 72% of normal, and while the spring peak displayed a typical timing, occurring on June 6, peak discharge was higher than average at 42.8 m^3/s or 136% of normal. In addition, an early spring peak of 26.2 m^3/s occurred on April 30.

Finally in 2002, the river regime was characterized as high-volume/high-peak. The total annual volume was considerably greater than average, estimated as 321,796,395 m^3 or 126% of normal. The spring runoff peak discharge of 83.8 m^3/s, or 267% of normal, occurred slightly later than was typical on June 19. There was a smaller, early spring peak of 10.0 m^3/s recorded on April 14.

Table 3. Flow summary for the Elbow River above Glenmore Reservoir, 1999-2002, and the 25-yr average.

Year	Annual Volume $10^6 m^3$	Peak Flow (m^3/s)	Date	Comments
1999	254.1	46.1	July 3	Normal volume, delayed peak
		53.8	July 16	
2000	156.9	18.6	June 9	Low volume, low peak
2001	183.2	42.8	June 6	Low volume, high peak
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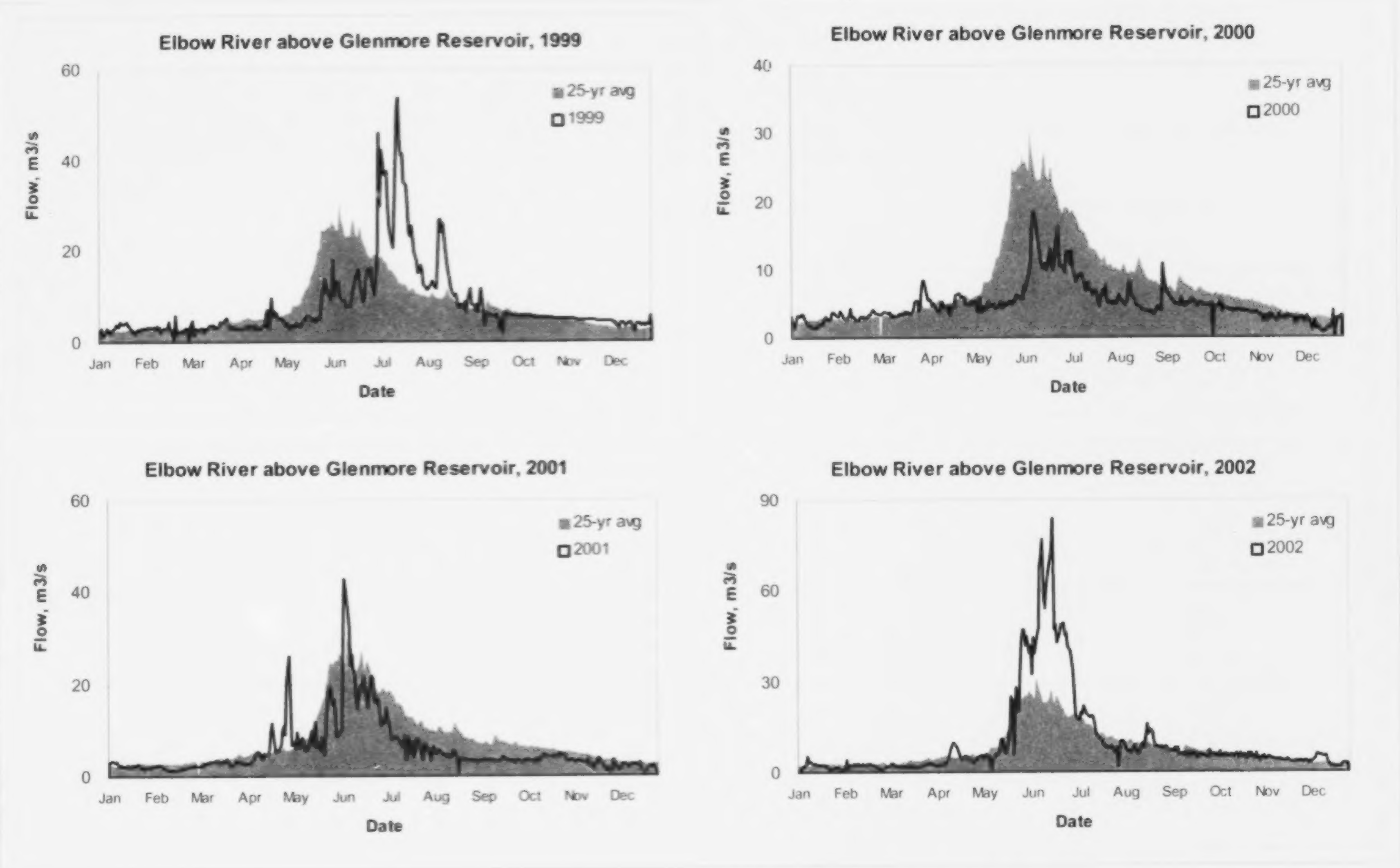

Elbow River above Glenmore Reservoir, 1999

Elbow River above Glenmore Reservoir, 2000

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Elbow River above Glenmore Reservoir, 2002

Figure 2. Elbow River above Glenmore Dam (Station 05BJ005) flows, 1999-2002 in relation to 25-year average river flows.

Tributary Flows

Tributary flows are summarized in Table 4. Median and peak flows at Pirmez Creek, Millburn Creek and Springbank Creek were consistent among years. Springbank Creek and Millburn Creek had the lowest flows among all tributaries, with medians from 0.01 to 0.03 m^3/s. Higher median flows were evident in 2002 at Prairie Creek, McLean Creek, and Lott Creek than in previous years. Among tributaries sampled for flow, Prairie and Bragg Creeks consistently exhibited the highest peak flows, with maximums of 4.11 m^3/s and 3.06 m^3/s respectively in 2001.

Table 4. Median and peak tributary flows (m^3/s) for upper Elbow River tributary sites: 1999-2002. Hyphens indicate not sampled for flow. Values in parentheses are sample sizes.

Tributary Sites		1999	2000	2001	2002
Little Elbow River	Median	-	-	-	-
	Peak	-	-	-	-
Prairie Creek	Median	0.21 (9)	-	0.21 (4)	0.49 (4)
	Peak	1.12	-	4.11	2.26
McLean Creek	Median	0.17 (10)	-	0.18 (5)	0.36 (4)
	Peak	0.67	-	1.18	1.17
Bragg Creek	Median	0.23 (21)	0.23 (23)	0.40 (7)	0.22 (20)
	Peak	1.61	0.49	3.06	1.61
Pirmez Creek	Median	0.38 (12)	0.39 (23)	-	0.44 (16)
	Peak	0.59	0.42	-	0.63
Millburn Creek	Median	0.03 (9)	0.03 (23)	-	0.03 (14)
	Peak	0.21	0.10	-	0.10
Springbank Creek	Median	0.02 (20)	0.01 (20)	0.02 (8)	0.01 (22)
	Peak	0.07	0.04	0.12	0.03
Lott Creek	Median	0.25 (21)	0.29 (23)	0.26 (8)	0.34 (21)
	Peak	0.43	0.41	0.34	0.76

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	Peak	0.43	0.41	0.34	0.76

Water Quality

Temperature

Water temperature strongly influences the chemical and biological processes in a stream. Temperature changes can alter the existing aquatic community, modifying algal, benthic, and fish communities, decreasing diversity, and increasing biological productivity (CCME, 2003). Higher temperatures decrease the solubility of oxygen in water, thereby decreasing the dissolved oxygen available to fish, and along with pH may affect the solubility of other chemical compounds (e.g. ionic salts) which can influence the effect on aquatic biota (McNeely et al., 1979; Hem, 1989).

Temperature is primarily influenced by the climatic regime, through solar radiation, precipitation, and air temperatures. However, thermal discharges from industrial sources or impoundments, or the amount of groundwater discharging to a stream can all impact the water temperature of a stream.

Elbow River Sites

Among Elbow River mainstem sites, water temperatures generally increased from the headwaters to Weaselhead Bridge (Figure 3). Temperatures were always lowest at the most upstream mainstem site, Cobble Flats, where median temperatures over the open-water sampling season varied little among years from 6.6 to 6.8 °C, and increased steadily from the headwaters to downstream sites. Temperatures were always greatest at the lower sites: at Weaselhead in 1999 and 2001, with median temperatures of 9.3 °C and 9.8 °C respectively, and at Glencoe GCC in 2000 at 12.3 °C, and Sarcee Bridge in 2002 at 9.6 °C.

Spatially, water temperatures did not vary significantly among mainstem sites for the first three years of the study ($P>0.05$). However, in 2002 there was a significant difference among sites as median temperature at the Hwy 22 Bridge was significantly lower than at Sarcee Bridge ($P<0.05$). Nevertheless, water temperatures were generally greater at sites further downstream (Figure 3). One exception to this pattern was the reach from Redwood Meadows to the Hwy 22 Bridge site where median temperatures consistently decreased in all years, with temperature decreases of 1.2 °C in 1999 and 2000, 1.9 °C in 2001 and 2.6 °C in 2002. The reason for the decline in water temperature at Highway 22 is not known, but one factor could be movement of groundwater into the Elbow River, which would generally be cooler than the river in summer. The alluvial aquifer is shallow and permeable, and significant groundwater-surface water interaction is expected to occur (C. Ryan, 2003, University of Calgary, personal communication).

The greatest increase in median temperature between adjacent sites occurred in the next downstream reach, between Hwy 22 Bridge and the Glencoe GCC, as medians increased 0.6 °C in 1999 and 3.3 °C to 3.5 °C in 2002 and 2000, respectively. Temperatures did not increase markedly among the lower mainstem sites, as median temperature increased from Twin Bridges to the Weaselhead Bridge from 0.2 °C to 0.5 °C in 1999, 2000, and 2002, and 1.4 °C in 2001.

Seasonally, temperatures followed a pattern generally coincident with ambient air temperatures, with low temperatures in the early season after ice-out, increasing steadily over the summer and decreasing during the fall. Water temperatures at the sites upstream from Hwy 22 generally peaked in early to mid-August, whereas the lower sites experienced maximum temperatures earlier in the summer from mid to late July.

Although neither the Canadian Water Quality Guidelines nor the Alberta Surface Water Quality Guidelines prescribe upper maximum temperatures for protection of freshwater life, European guidelines (EIFAC, 1965 in CCME, 2003) generally consider the upper temperature limit to protect salmon and trout as 20-21 °C. During this study, no mainstem temperatures approached or exceeded this guideline, as maximums in the upper mainstem sites ranged from 6.5 to 10 °C among all years, and in the lower sites from 12 to 18.0 °C (Figure 3). Among all sites, maximum water temperatures at Twin Bridges were consistently the highest, ranging from 15.6 °C in 1999 to the overall study

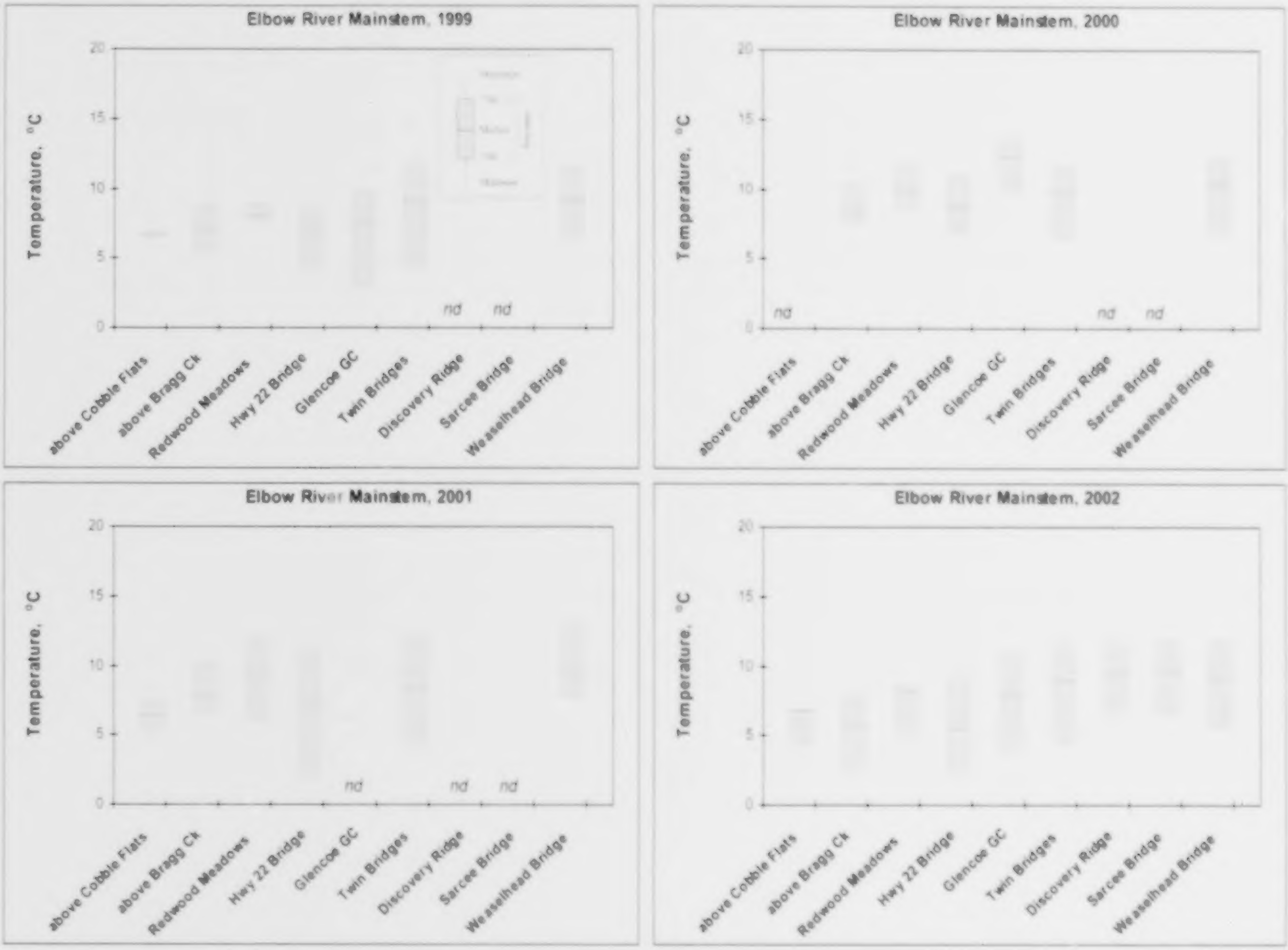


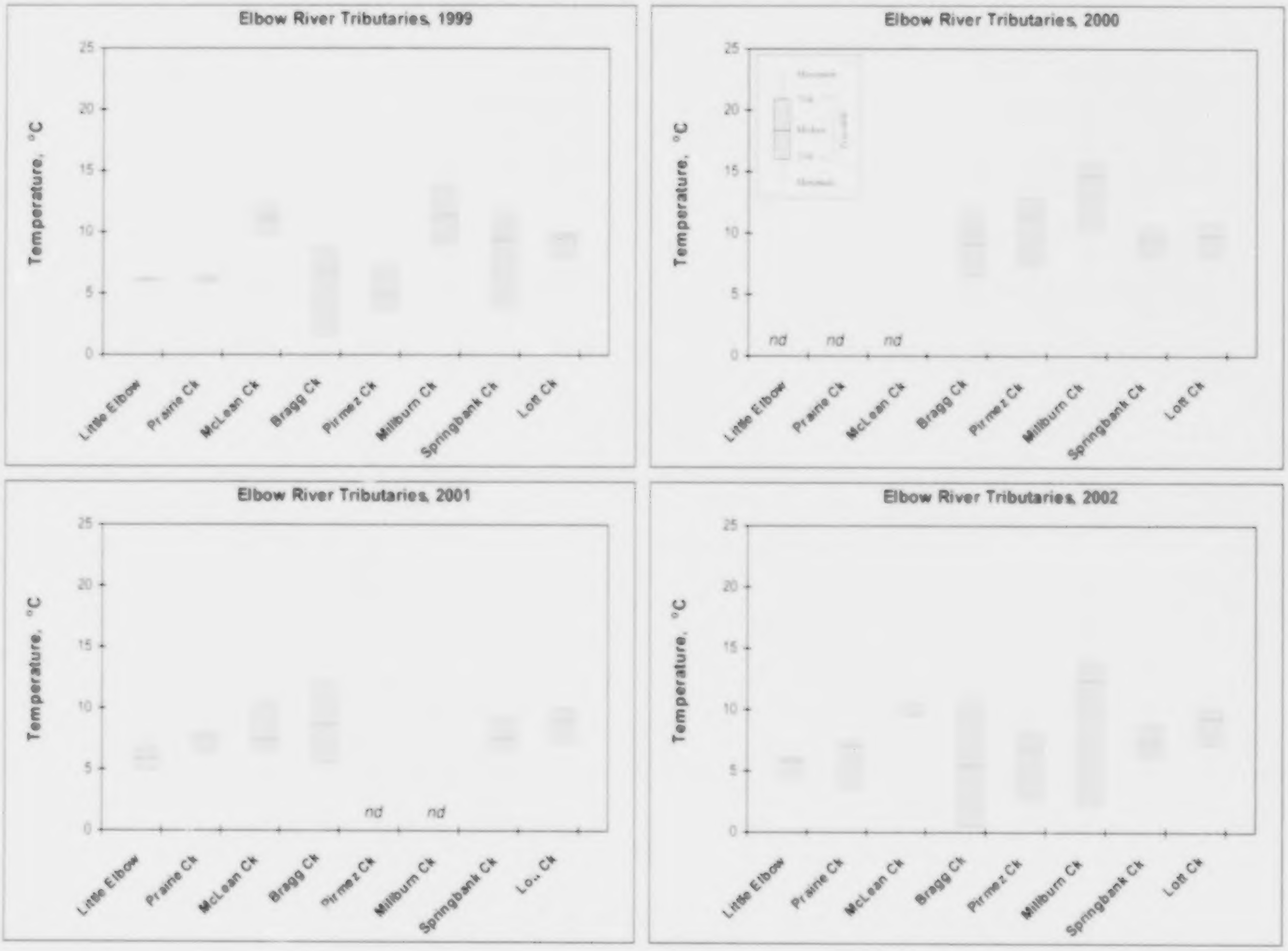
Figure 3. Temperature at Elbow River mainstem sites: March to September, 1999-2002 ***(nd=no data).***

maximum of 18.0 °C recorded in July 2001. However, median water temperatures were higher at Weaselhead Bridge than at Twin Bridges from 1999 to 2001.

Elbow River Tributary Sites

Upper tributary sites, such as the Little Elbow River, Prairie Creek and Bragg Creek displayed low and usually constant water temperatures among years, with medians varying from 6 °C to 9 °C (Figure 4). Temperatures in McLean Creek and Pirmez Creek were intermediate and more variable, with McLean Creek ranging from 7 °C to 11 °C, and Pirmez Creek from 5 °C to 12 °C. Springbank and Lott Creeks had similarly moderate water temperatures, but were consistent among years, ranging from 7 °C to 10 °C. Millburn Creek routinely presented the highest temperatures, with a median of 11 °C in 1999 significantly greater than the Little Elbow, Prairie, Bragg, and Pirmez Creeks ($P<0.05$), and 15 °C in 2000, which was significantly greater than Bragg, Pirmez and Lott Creeks ($P<0.05$). There were no significant differences in tributary stream temperatures among sites in 2001 or 2002 ($P>0.05$).

Similar to seasonal water temperature patterns in the Elbow River mainstem, tributary temperatures followed the pattern of ambient air temperatures, increasing from lows at or near 0 °C after ice-out


Elbow River Tributaries, 1999

Elbow River Tributaries, 2000

Elbow River Tributaries, 2001

Elbow River Tributaries, 2002

Figure 4. Temperature at Elbow River tributary sites: March to September, 1999-2002 *(nd=no data)*.

in March to maximums in July and August, and decreasing to September. The uppermost tributaries, Little Elbow River and Prairie Creek, displayed maximum temperatures in August, whereas maximums in the lower reach tributaries occurred in either June or July. Maximum temperatures at the Little Elbow River and Prairie Creek ranged from 7 °C to 8 °C among all years, McLean, Bragg and Lott Creeks had maximums from 12 °C to 16 °C, Pirmez Creek from 9 °C to 17 °C, with Millburn Creek consistently exhibiting the greatest maximum water temperatures from 17 °C to 22 °C (Figure 4).

Among all tributaries and years, only one sample at one site exceeded the European guideline of 20-21° C for salmonid streams (EIFAC, 1965 in CCME, 2003), that being Millburn Creek with a temperature of 22.4 °C recorded on one date in July 2000.

Dissolved Oxygen

Dissolved oxygen is an important water quality variable with respect to the distribution and abundance of fish and aquatic life in freshwater systems. Sources of dissolved oxygen include the atmosphere and photosynthesis by algae and higher aquatic plants.

Dissolved oxygen concentrations in freshwater are related to stream temperatures, increasing substantially in cold water, salinity, turbulence, atmospheric pressure, and the presence of oxygen-depleting substances, which may include degrading organic material from aquatic plants and wastewater inputs (McNeely et al., 1979; Hem, 1989).

The Canadian Water Quality guidelines have established dissolved oxygen criteria for the protection of freshwater aquatic life (cold-water biota): a minimum concentration of 9.5 mg/L to protect early life stages and 6.5 mg/L for other life stages (CCME, 2003).

Elbow River Sites

Dissolved oxygen concentrations in the Elbow River were consistently high at all mainstem sites each year, with medians varying from 9.3 mg/L at Twin Bridges in 2000 to 11.3 mg/L at Hwy 22 Bridge in 1999 (Figure 5). The lowest value of 5.8 mg/L was recorded in 2001 at the Twin Bridges site, and an overall maximum of 14.1 mg/L at the Redwood Meadows site in the same year.

In the first three years of the study (1999-2001), there appeared to be no consistent longitudinal pattern in dissolved oxygen, nor were there statistically significant differences among mainstem sites ($P>0.05$). However, in 2002 median dissolved oxygen concentrations declined from the headwaters to Weaselhead Bridge (Figure 5). Dissolved oxygen concentrations at Discovery Ridge and Sarcee Bridge at 9.5 mg/L were significantly lower than the upstream sites, Elbow River above Bragg Creek (median 10.5 mg/L) and the Hwy 22 Bridge (median 10.6 mg/L) ($P<0.05$).

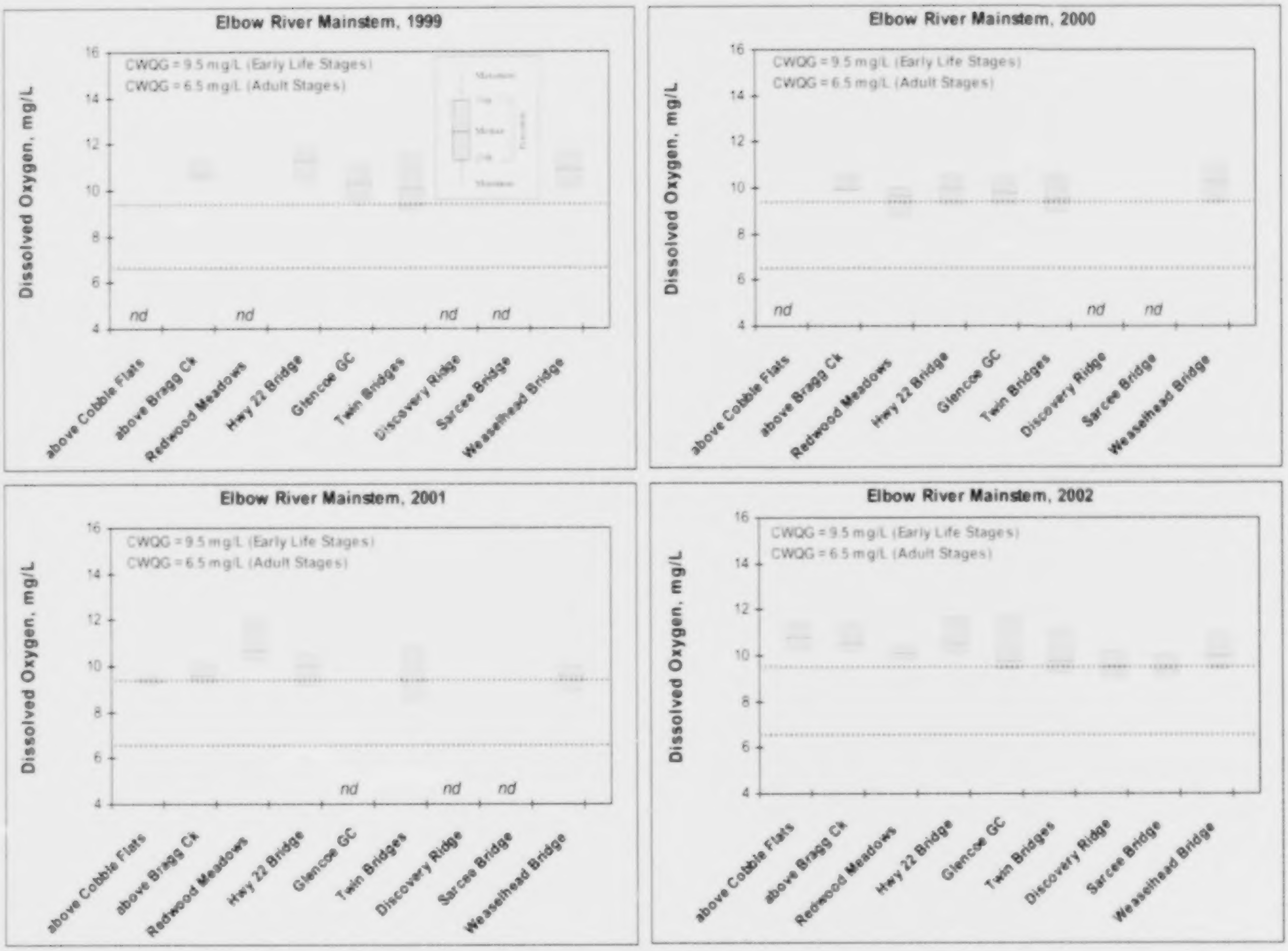
Dissolved oxygen concentrations in water in equilibrium with the atmosphere are typically inversely related to temperature since gas solubility decreases with increasing temperatures. Seasonally, dissolved oxygen concentrations varied inversely with water temperature, with the highest concentrations early in the season, usually in March or April. Concentrations decreased thereafter to minimums in mid-summer, and again increased slightly as water temperature declined in September.

Among all sites and years, 33% of all samples failed to meet the 9.5 mg/L guideline recommended for early life stages of cold-water biota (CCME, 2003), with a consistent increase in non-compliance rate at sites further downstream. In 2002, for example, sites above the Hwy 22 Bridge experienced a low non-compliance rate from 0 to 5% of samples failing to attain 9.5 mg/L, with rates increasing to 14% at the Hwy 22 Bridge, 38% at the Glencoe GCC, 42% at Twin Bridges, 53 to 58% at Discovery Ridge and Sarcee Bridge, decreasing to 31% at the Weaselhead. The timing of these non-compliance instances was largely confined to the months of July and August. It should be noted that this guideline should only be applied where spawning by fish species that bury their eggs in gravel is known to occur and while the eggs and larvae remain in gravel.

There were only two instances of samples failing to meet the suggested 6.5 mg/L dissolved oxygen guideline for late-stage cold-water biota (CCME, 2003), and these both were only marginally below the stated guideline value. A dissolved oxygen concentration of 5.8 mg/L was recorded at Twin Bridges in August 2001, and a value of 6.5 mg/L at the Glencoe GCC in July 2002 (Figure 5). The high incidence of compliance with guidelines indicates a suitable dissolved oxygen regime throughout the upper Elbow mainstem for adult life stages of cold-water fish during the years of this study.

Elbow River Tributary Sites

Dissolved oxygen concentrations in the tributaries to the Elbow River were consistently high among all sites and years, with medians ranging from 7.9 mg/L at Lott Creek in 2001 to 11.3 mg/L at Bragg Creek in 1999 and the Little Elbow River in 2002 (Figure 6).


Elbow River Mainstem, 1999

Elbow River Mainstem, 2000

Elbow River Mainstem, 2001

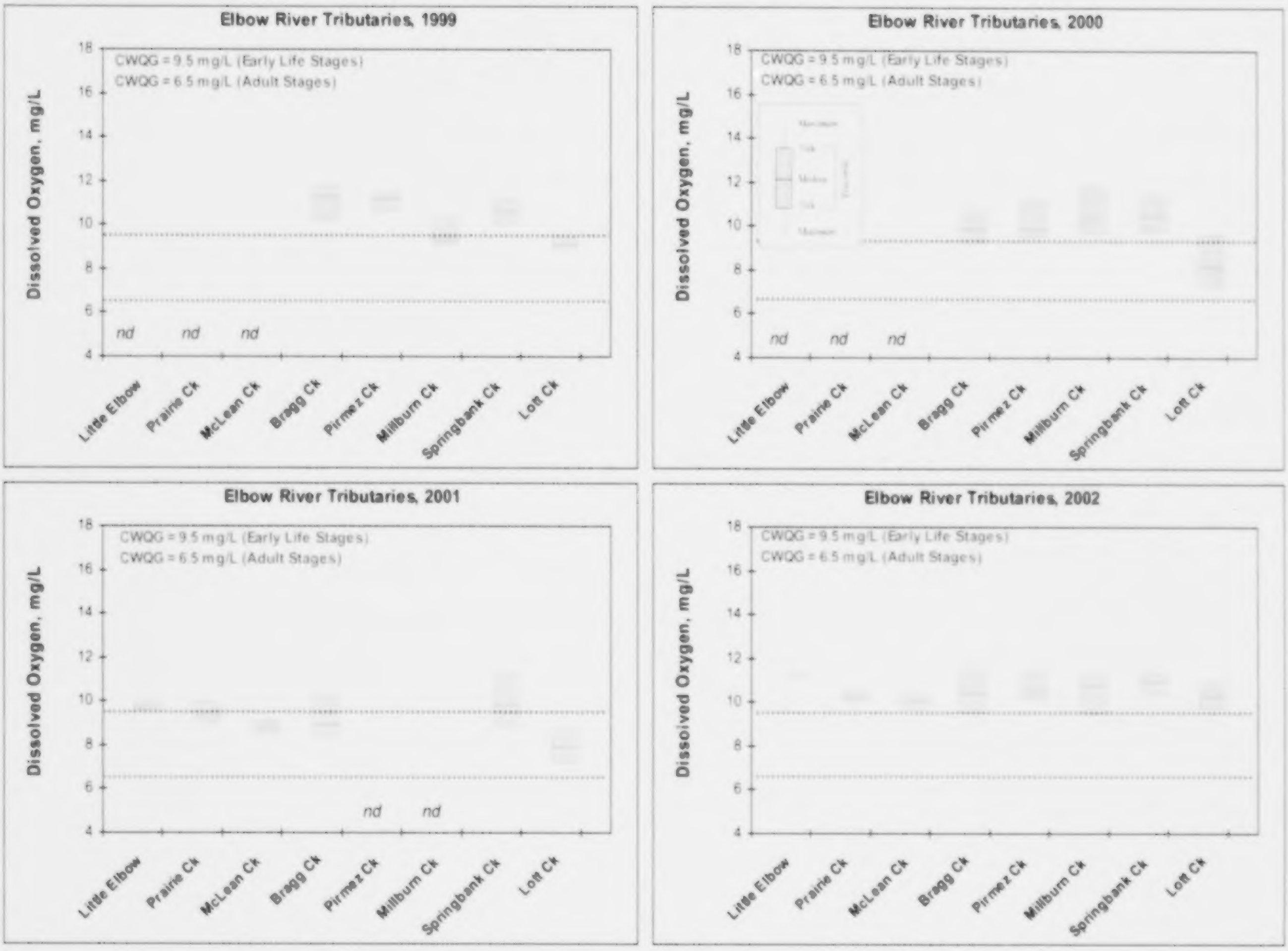
Elbow River Mainstem, 2002

Figure 5. Dissolved oxygen at Elbow River mainstem sites: March to September, 1999-2002 *(nd=no data).*

Spatially, there appeared to be no consistent pattern in dissolved oxygen concentrations from tributaries in the upper reaches to the lower (Figure 6). In 2002, for example, site medians varied little, and ranged from a high of 11.3 mg/L at the Little Elbow River to a low of 10.3 mg/L at Lott Creek.

In most years, Lott Creek exhibited the lowest dissolved oxygen concentrations among all tributary sites sampled. In 1999 and 2000 alone, dissolved oxygen concentrations were significantly different among sites (*P*<0.05), with Lott Creek exhibiting significantly lower median concentrations of 9.1 mg/L and 8.1 mg/L in both years, respectively, than Bragg Creek, Pirmez Creek, Millburn Creek (2000 only), and Springbank Creek (*P*<0.05).

On a seasonal basis, dissolved oxygen concentrations followed the temperature regimes of the respective streams, high in the early season with low temperatures, decreasing to the summer months as temperatures increased, and again decreasing to fall with declining temperatures. Maximum dissolved oxygen concentrations generally varied from 10.3 mg/L to 13.9 mg/L (Figure 6), with peaks occurring in April through to early June. However, the highest dissolved oxygen concentration recorded during the study was 16.8 mg/L on July 13, 2000 in Millburn Creek, possibly related to increased instream biological productivity. In addition, minimum


Elbow River Tributaries, 1999

Elbow River Tributaries, 2000

Elbow River Tributaries, 2001

Elbow River Tributaries, 2002

Figure 6. Dissolved oxygen at Elbow River tributary sites: March to September, 1999-2002 (*nd=no data*).

concentrations usually occurred during the summer months of July and August. Overall, the lowest dissolved oxygen concentrations were found in Lott Creek, ranging from 5.7 mg/L in 1999 to 6.4 mg/L in 2002, all occurring in either August or September.

pH

The effective concentration, or activity, of hydrogen ions in water is represented by the measure pH. This variable indicates the balance between acids and bases in water, and reflects the solvent power of water, thereby indicating its possible chemical reaction on rocks and soils (McNeely et al., 1979; Hem, 1989). The pH of water may influence the species composition of an aquatic environment, and can affect the availability of nutrients and relative toxicity of many trace elements (McNeely et al., 1979).

For the protection of the aquatic environment, Canadian Water Quality Guidelines recommend that pH should not vary beyond the range of 6.5 to 9 (CCME, 2003).

Elbow River Sites

In the Elbow River, pH fluctuated over a narrow range, differing only slightly among sites and among years, with medians in the range of 8.0 to 8.3 (Figure 7). Absolute ranges of pH were similarly narrow, varying from overall lows of 7.5 in mid-July 2002 at the Glencoe GCC to a high of 8.6 at the Weaselhead on May 31, 2000. The majority of pH measurements fell within the range of 8.1 to 8.3. No samples fell outside the Canadian Water Quality Guidelines of 6.5 to 9.

There was no apparent longitudinal pattern in pH. There were, however, statistically significant differences in median pH among sites for 1999, 2000, and 2002 ($P<0.05$). pH at the Elbow River above Bragg Creek was significantly lower than the downstream sites at Twin Bridges and Weaselhead Bridge in 1999 ($P<0.05$), Hwy 22 Bridge, Twin Bridges and Weaselhead Bridge in 2000 ($P<0.05$), and Sarcee Bridge and Discovery Ridge in 2002 ($P<0.05$). In 2002, pH at the Glencoe GCC was significantly lower than its adjacent sampling sites, Hwy 22 Bridge above and Twin Bridges below ($P<0.05$).

There was no consistent pattern in seasonality of pH among sites and years. In 1999 and 2001, maximum pH in the upstream sites (Hwy 22 Bridge and above) generally occurred after the spring runoff in June/July, with minimums prior to this period. In the same years, downstream sites showed the opposite, with maximum pH reported prior to the June/July mountain snowmelt runoff and minimums later. In 2000 and 2002, a more consistent pattern of seasonality was evident, with maximum pH at most sites occurring in July or August, and minimums earlier in the season, generally in May preceding the June runoff.

Elbow River Tributary Sites

Similar to the pH in the Elbow River mainstem, tributary pH was relatively constant among sites and among years, displaying a narrow range of medians from 7.5 at Lott Creek to 8.3 and 8.4 at the Little Elbow and Prairie Creeks, respectively (Figure 8). All tributary pH measurements were within the recommended Canadian Water Quality Guideline of 6.5 to 9.

In all years there were significant differences among sites in pH ($P<0.05$). The Little Elbow River and Prairie Creek were the tributaries with highest pH in 2001 and 2002, with medians of 8.3 to 8.4 respectively at both sites in both years, significantly greater than McLean and Lott Creeks in 2000, and all other tributaries except McLean Creek in 2002 ($P<0.05$). In all years, pH in Lott Creek was consistently low, with medians from 7.5 to 7.9, significantly lower than most of the tributaries that drained to the river above it. In particular, pH in Lott Creek was significantly less than Pirmez, Millburn and Springbank Creeks in 1999 ($P<0.05$), all other tributaries sampled in 2000 ($P<0.05$), and lower than all others except McLean Creek in 2000 and Pirmez Creek in 2002 ($P<0.05$).

There was no consistent pattern in pH seasonality among tributary sites or among years, as there was a limited range between minimums and maximums at most sites, varying from 8.1 to 8.5 at the Little Elbow River and Prairie Creek, from 7.3 to 8.6 in the mid-reach tributaries of McLean Creek, Bragg Creek, Pirmez Creek, Millburn Creek and Springbank Creek, and from 6.9 to 8.3 at Lott Creek (Figure 8).

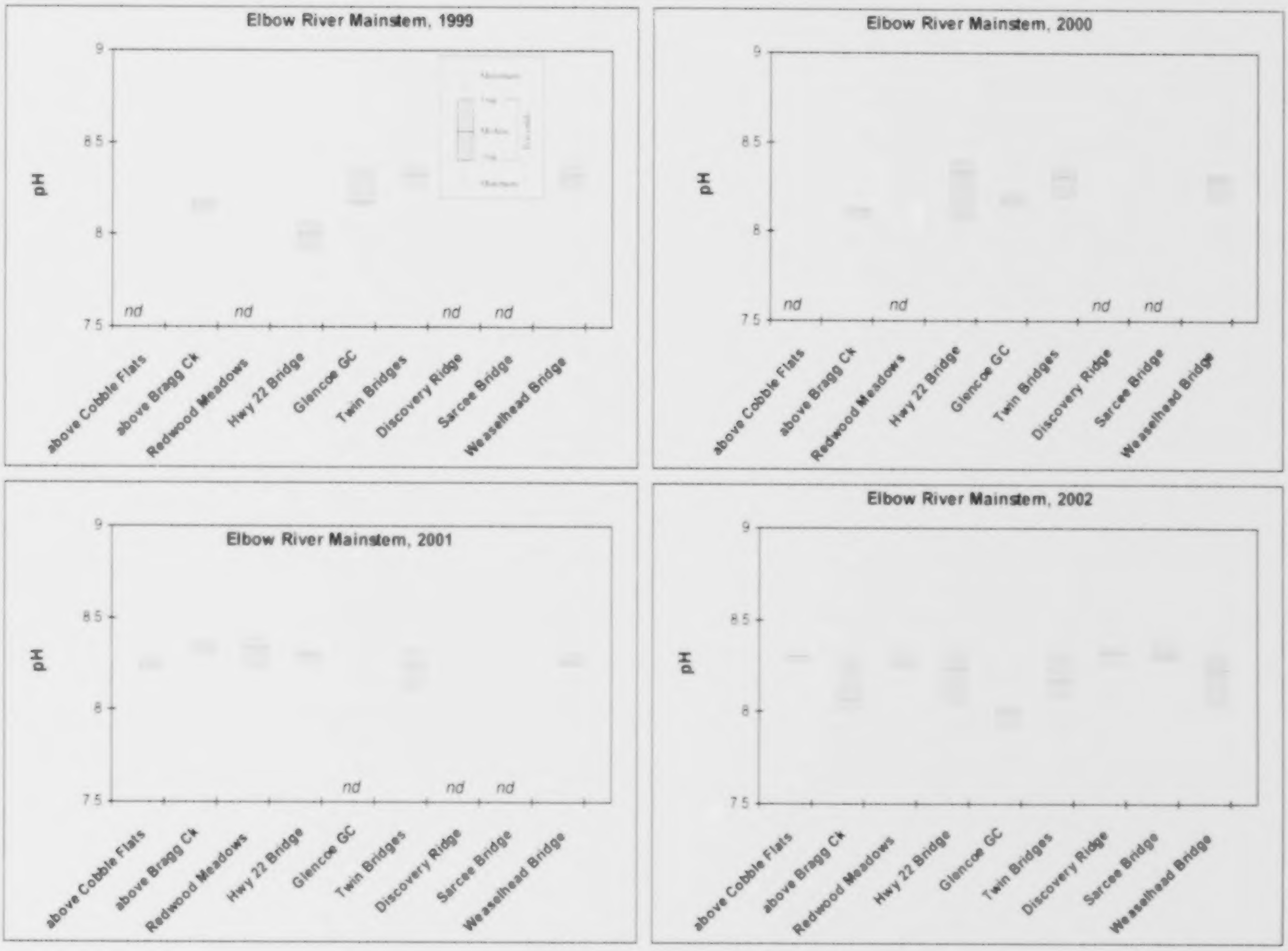


Figure 7. pH at Elbow River mainstem sites: March to September, 1999-2002 *(nd=no data).*

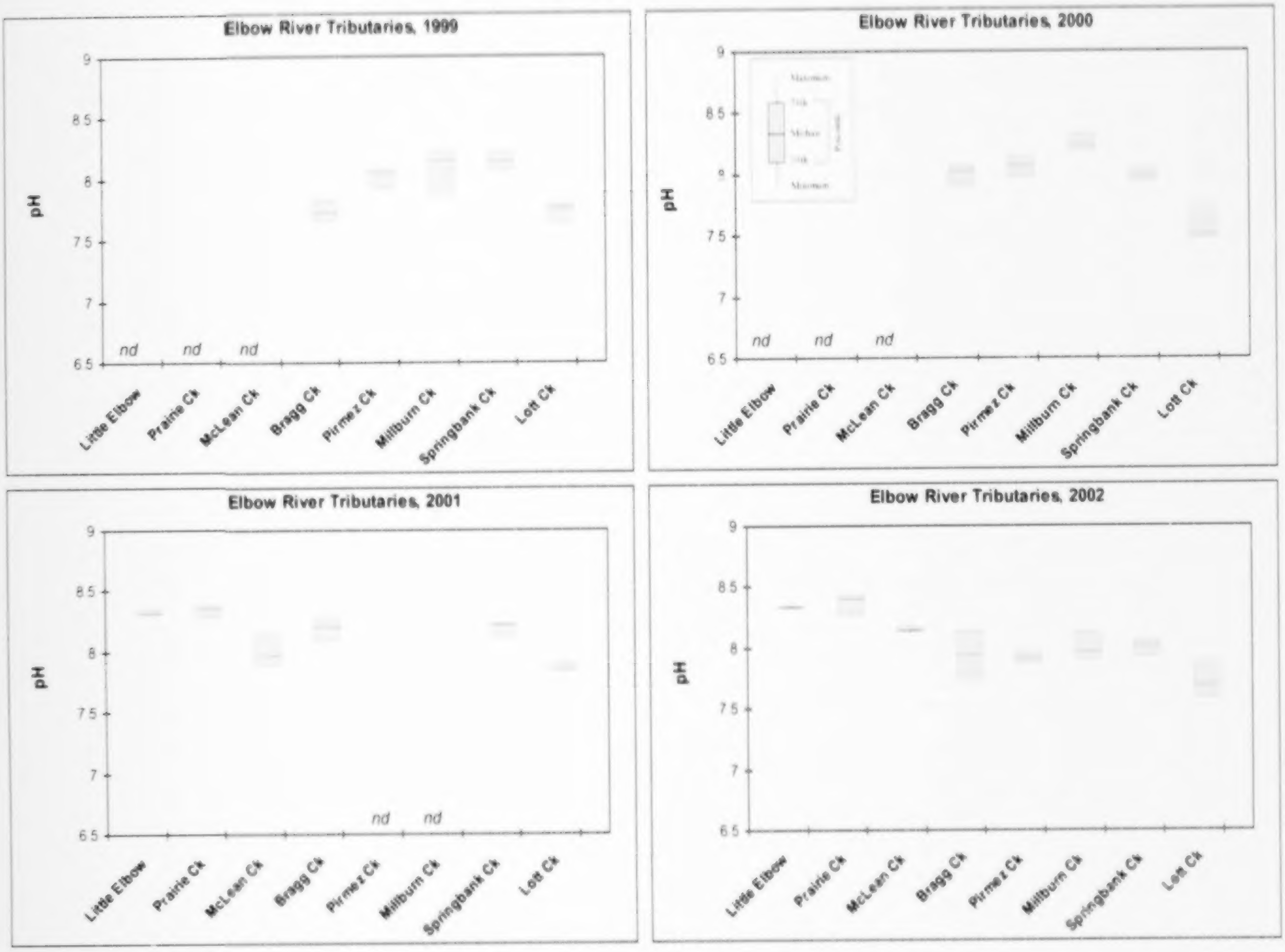


Figure 8. pH at Elbow River tributary sites: March to September, 1999-2002 *(nd=no data).*

Conductivity

Conductivity, or specific conductance, is a measure of the ability of water to conduct an electrical current. Because the presence of charged ionic species in solution makes the solution conductive, this variable provides an indication of total dissolved solids or ionic concentration of the water (Hem, 1989).

Sources of conductivity can include underlying geology of the watershed, influence of groundwater, glacial meltwater, and anthropogenic inputs including runoff from agriculture and roads, wastewater, or septic system effluents (McNeely et al., 1979). River discharge will also influence conductivity of the water, with higher discharges contributing to lower conductivities through the dilution of ion concentrations.

High specific conductance of water generally indicates a high dissolved solids concentration although it provides no indication of the composition of the various ions comprising the dissolved solids. In the Elbow River, major ions present are magnesium, calcium, sodium, potassium, carbonate, bicarbonate, chloride, and sulphate (Beers and Sosiak, 1993).

No surface water quality guidelines exist for conductivity in Canada or Alberta, largely because of the variable nature of conductivity.

Elbow River Sites

In all years, Elbow River mainstem sites displayed a longitudinal pattern of conductivity, with low conductivities at the upper sites, increasing downstream to Twin Bridges and remaining relatively constant thereafter (Figure 9). Among all years, median conductivity in the Elbow River above Bragg Creek ranged from 277 µS/cm to 365 µS/cm, while the Elbow River at Weaselhead ranged from 324 µS/cm to 402 µS/cm. Among-site differences were evident in all years. Conductivity in the Elbow River at Weaselhead was significantly greater than at sites upstream from Hwy 22 Bridge in 1999 through 2001 ($P<0.05$), and Twin Bridges median conductivities were significantly greater than upstream sites in 2000 and 2001 ($P<0.05$).

Lower conductivities in the upper sites are likely a consequence of their proximity to the source of meltwater, either glacial or headwater snowpack, and overall lack of nonpoint or tributary inputs. With distance downstream, greater cumulative inputs from nonpoint sources and tributary inputs became increasingly evident. Within any one individual site and year, there was typically a limited range of conductivities experienced through the season. In 1999 to 2001, seasonal ranges (i.e. difference of minimum and maximum conductivity through the sampling season) were measured from 85 to 153 µS/cm (Figure 9). In 2002, overall conductivities were lower than in previous years; however absolute ranges were greater, from 67 to 220 µS/cm. These differences were largely a result of a wetter year in 2002 with consequently higher river discharges through the season.

Lower conductivities coincided with peak river discharges: early to mid-July in 1999 and early to mid-June in 2000 to 2002. After the spring runoff peak, conductivities increased to their seasonal maximum by mid-September. Occasionally, peak conductivities were found before runoff in May.

Elbow River Tributary Sites

In all years, tributary sites in the upper reaches of the watershed, the Little Elbow River to Bragg Creek, displayed low and relatively constant conductivities, with median values at Bragg Creek significantly lower than all downstream tributaries ($P<0.05$), and varying from 269 µS/cm in 2002 to 361 µS/cm in 1999 (Figure 10). In the mid and lower reaches of the Elbow River, higher median tributary conductivities were evident, ranging from 411 to 451 µS/cm at Pirmez Creek, 412 to 505 µS/cm at Millburn Creek, and 456 to 483 µS/cm at Lott Creek. In all years, Springbank Creek consistently displayed significantly higher conductivities than all other tributaries ($P<0.05$), with seasonal medians of 866 µS/cm in 2000, and ranging from 644 to 674 µS/cm in 1999, 2001 and 2002.

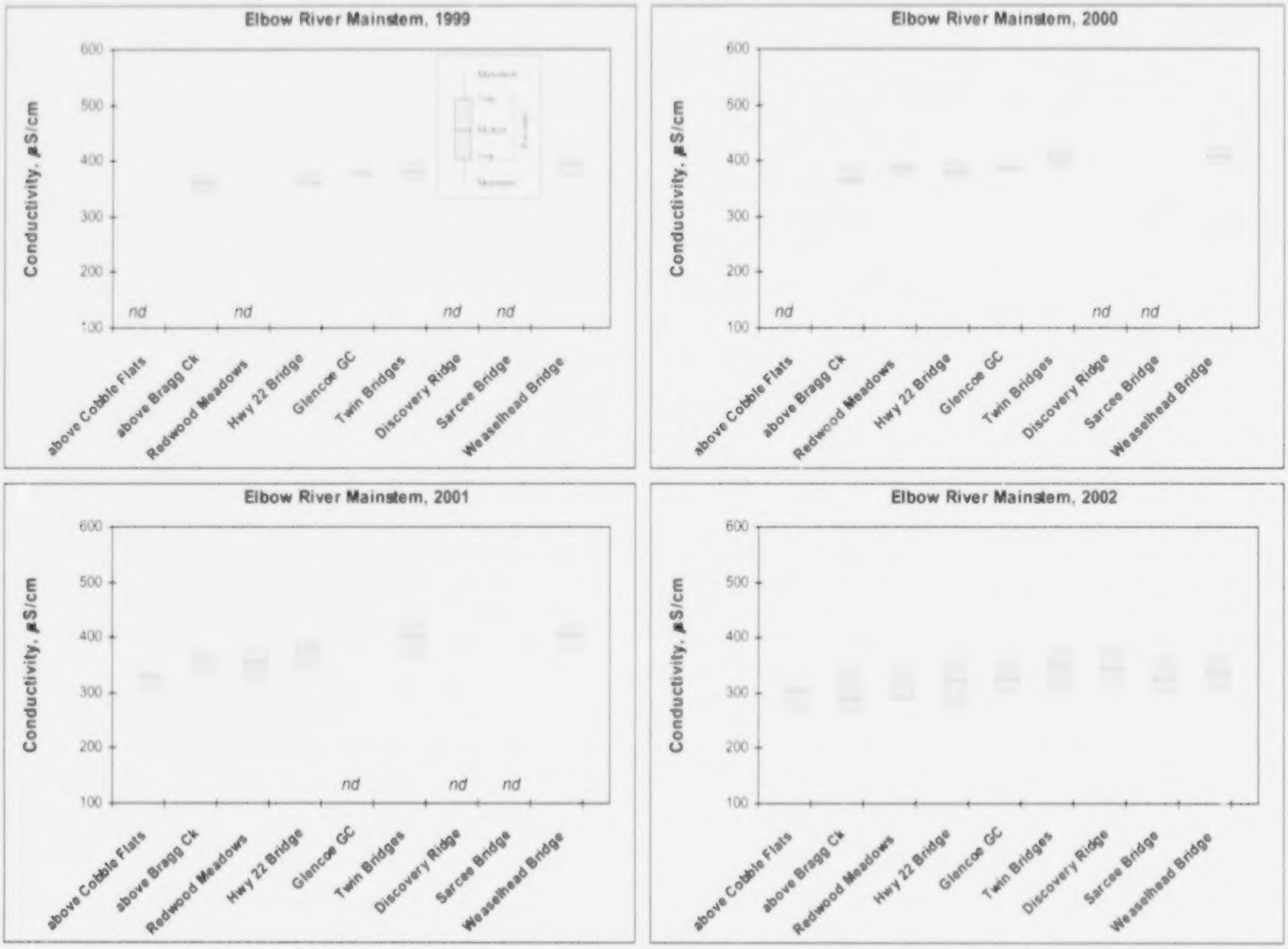


Figure 9. Conductivity at Elbow River mainstem sites: March to September, 1999-2002 (*nd=no data*).

Seasonally, tributaries in the upper reaches tended to have maximum conductivities late in the sampling season, generally August and September, with minimums occurring prior to the June runoff in mid to late May or early June. Tributaries in the lower reaches displayed no consistent seasonal pattern among sites or years, although Springbank Creek generally peaked in conductivity in early June before or during the mainstem runoff period, and minimum conductivity occurred later in the season from late July through September.

Absolute ranges in tributary conductivities were generally greater than in the Elbow River, especially in some of the mid or lower reach sites (Figure 10). Pirmez and Lott Creek displayed the narrowest of ranges, from 325 to 509 µS/cm among all years, perhaps because these streams are spring-fed. In the upper tributaries, (Little Elbow River, Prairie Creek, McLean Creek and Bragg Creek) conductivities ranged from a low of 134 µS/cm at Bragg Creek in 2002 to a maximum of 476 µS/cm at McLean Creek in 2001. Springbank Creek exhibited the greatest range and also the highest overall conductivity measured, with a low of 245 µS/cm in 2002 and a high of 1428 µS/cm in 2001.

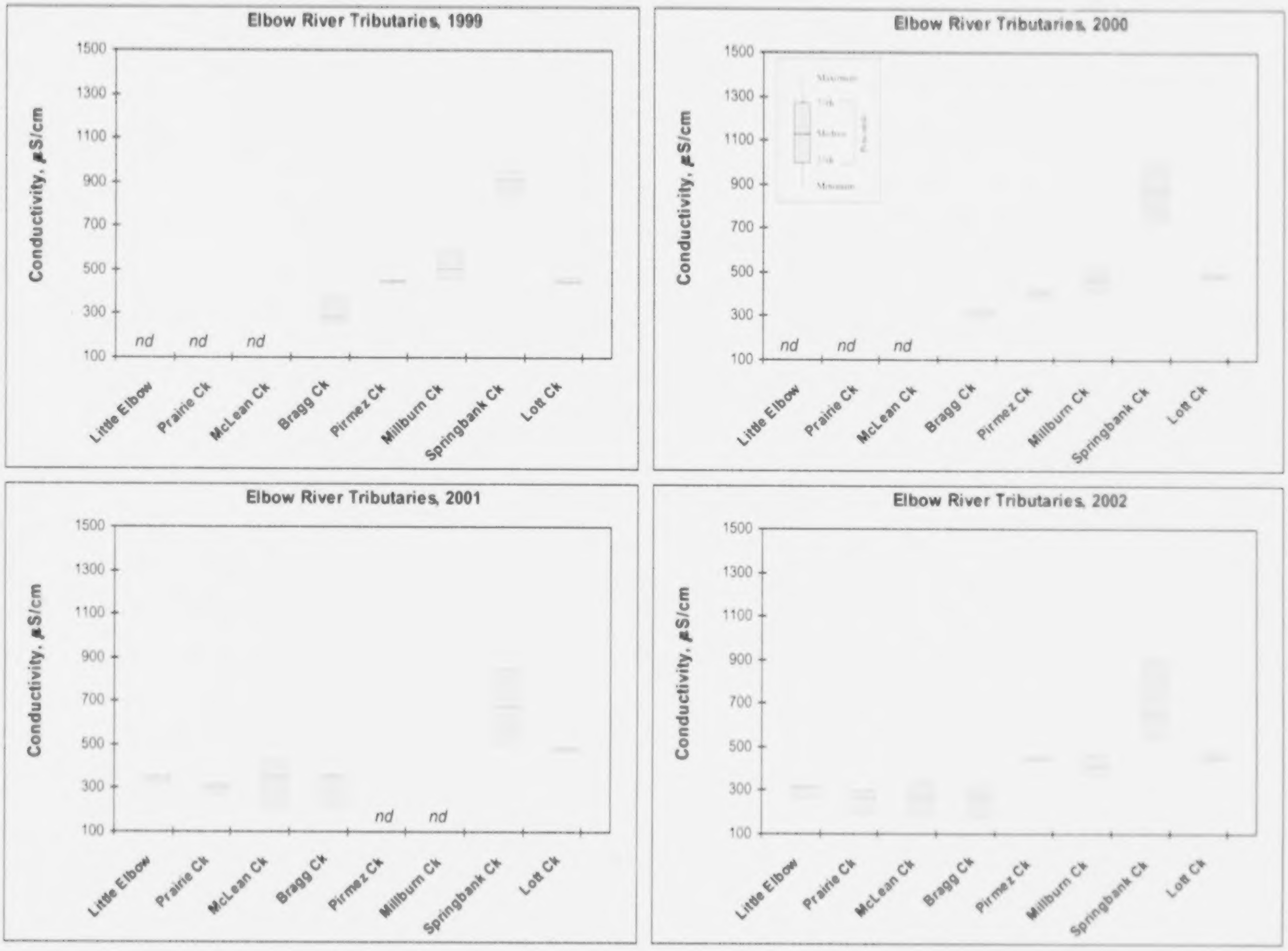


Figure 10. Conductivity at Elbow River tributary sites: March to September, 1999-2002 (*nd=no data*).

Total Organic Carbon

Organic carbon, composed of both dissolved and particulate forms, arises primarily from plant photosynthesis with bacterial fixation contributing to a lesser degree (CCME, 2003). Humic substances and degraded plant and animal material comprise the major proportion of organic carbon in water, with sources which include organic matter in soils, inputs of leaf litter, aquatic vegetation and other organisms, and runoff from agricultural and municipal and industrial waste discharges (McNeely et al., 1979; CCME, 2003). Organic carbon is an important consideration from a water treatment perspective because it increases coagulant and chlorine demand, and is a source of organic precursors to potentially harmful disinfection by-products (Peterson et al., 1993).

Elbow River Sites

Total organic carbon (TOC) in the Elbow River was relatively consistent among sites and years. There was a slight increasing longitudinal pattern, as medians varied from 1.2 mg/L to 1.5 mg/L at the two downstream sites, Twin Bridges and Weaselhead Bridge, in 1999, and from 0.5 mg/L at Cobble Flats to 1.3 mg/L at the Weaselhead Bridge among the remaining years (Figure 11). There were no significant differences in TOC concentration among mainstem sites in 1999, 2000, and 2002 ($P>0.05$). In 2001, significant differences in TOC existed among sites, with both Twin Bridges and Weaselhead Bridge median concentrations of 1.1 to 1.3 mg/L significantly greater than the upstream sites ($P<0.05$), which ranged from 0.5 to 1.0 mg/L.

There was a strong seasonal component to TOC concentration, with maximum values regularly associated with the runoff period, either during the early spring local snowmelt or the June/July mountain snowmelt event. Peak concentrations of 4.8 to 5.0 mg/L at Twin Bridges and Weaselhead Bridge (Figure 11) were coincident with the early July runoff period in 1999. However, in 2000 and 2001, maximum concentrations from 5 to 5.7 mg/L occurred at these sites during early local snowmelt in late March or early April. Peak concentrations in the upper watershed above the Hwy 22 Bridge site in 2000 and 2001 and all sites in 2002 were coincident with the mountain snowmelt runoff of late May to mid-June.

Elbow River Tributary Sites

Tributary TOC concentrations varied considerably among sites and among years (Figure 12). Low median concentrations of 0.3 mg/L occurred in the Little Elbow in 2001 and 2002. Intermediate concentrations occurred from 1.4 to 1.8 mg/L at Lott Creek in all years, and 2.3 to 2.5 mg/L at Prairie Creek in 2001 and 2002. Higher concentrations occurred at Springbank Creek from 2.5 to 3.7 mg/L and Bragg Creek from 3.7 to 4.2 mg/L, both in 2001 and 2002. The highest TOC concentrations were found in McLean Creek, with median concentrations from 6.7 to 7.6 mg/L in 2001 and 2002. TOC was not measured in Pirmez or Millburn Creeks in any year.

Significant differences in TOC were found among tributary sites in 2000, 2001, and 2002 ($P<0.05$). In 2000, Bragg and Springbank Creeks had significantly higher TOC concentrations than Lott Creek ($P<0.05$). In both 2001 and 2002, the Little Elbow River had the lowest TOC concentrations, significantly less than McLean, Bragg and Springbank Creeks ($P<0.05$).

Seasonally, TOC concentrations in the tributaries peaked early in the season, either before the June mountain snowmelt runoff period in 2000 and 2002, or during the primary spring runoff as in 2001. Maximum concentrations ranging from 5.6 mg/L at Bragg Creek and 6.9 mg/L at Springbank Creek (Figure 12) occurred in mid-May of 2000. In 2001, most maximums, varying from 14.2 mg/L TOC at Prairie Creek to 17.4 mg/L at Springbank Creek, occurred during the early June runoff, although the overall maximum concentration for that year of 18.0 mg/L was recorded at McLean Creek in early May. TOC concentrations usually peaked in mid-May to early June of 2002, with values ranging from a low of 0.9 mg/L at the Little Elbow and 1.8 mg/L at Lott Creek, to substantially higher concentrations of 7.5 mg/L at Springbank Creek to 13.5 mg/L at McLean Creek.

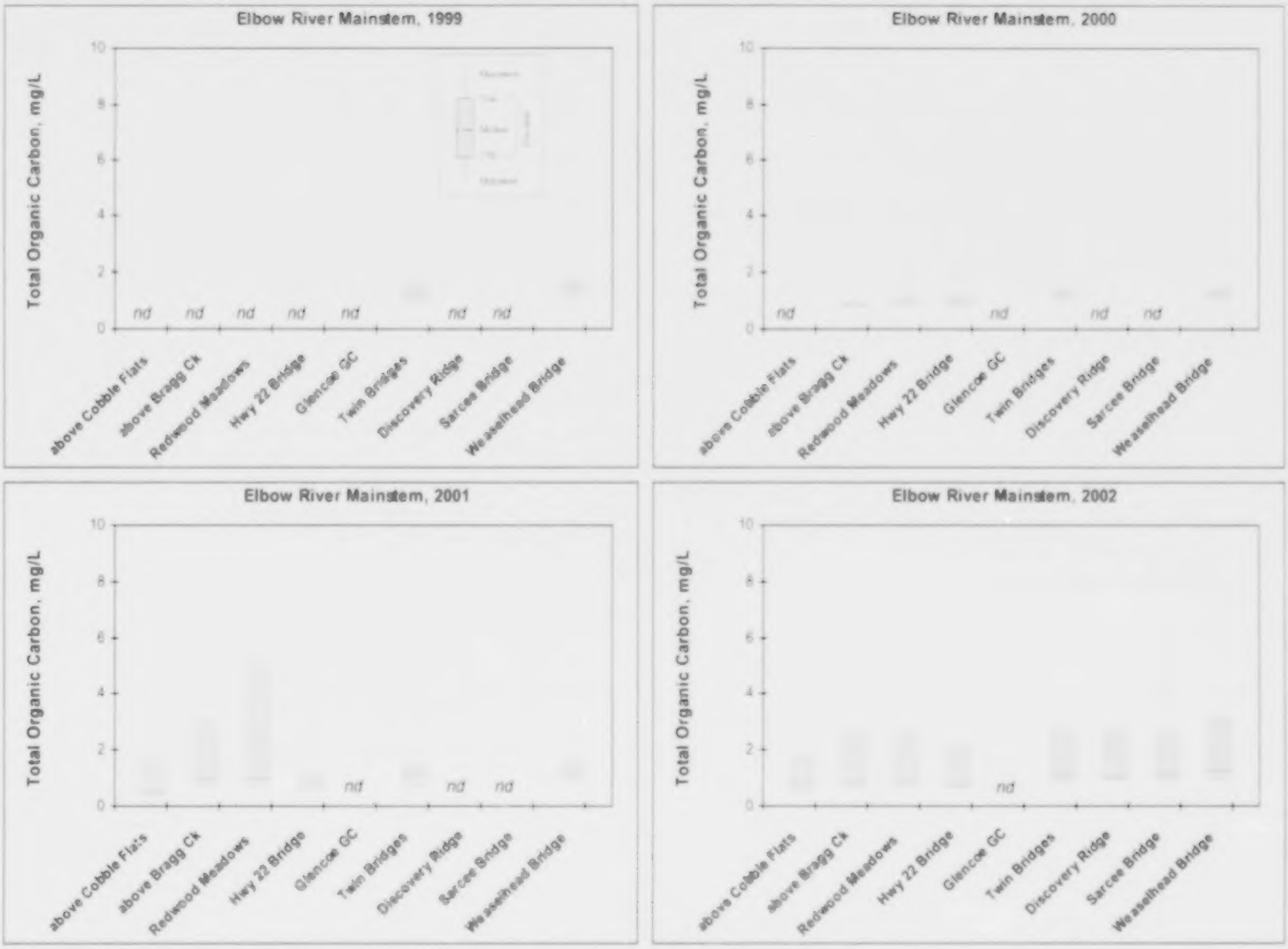


Figure 11. Total organic carbon at Elbow River mainstem sites: March to September, 1999-2002 (*nd=no data*).

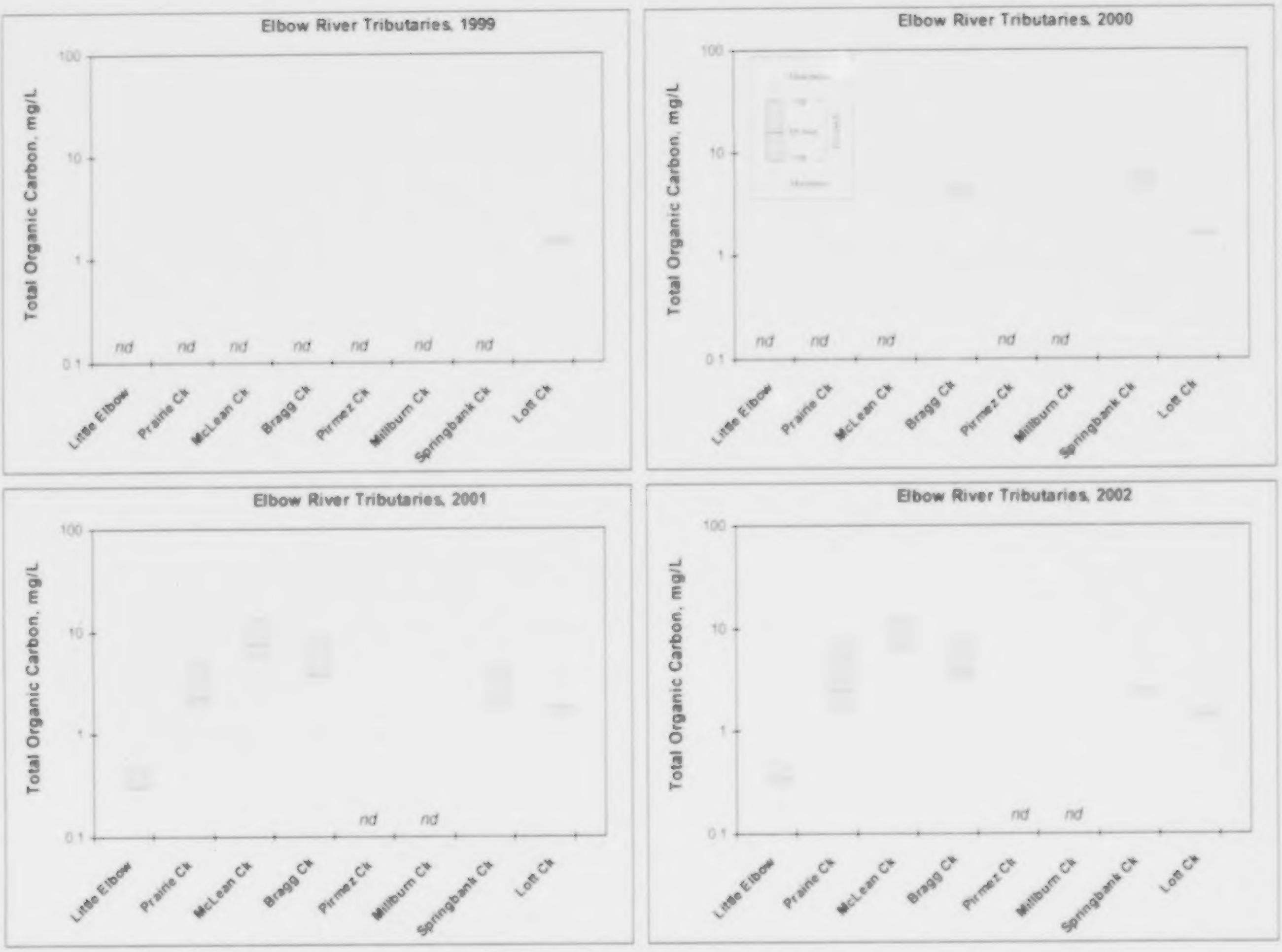


Figure 12. Total organic carbon at Elbow River tributary sites: March to September, 1999-2002 (*nd=no data*).

Phosphorus

Phosphorus and nitrogen are both essential plant nutrients. Phosphorus is often the limiting nutrient that stimulates the growth of algae and other plants in aquatic systems, and is often the cause of eutrophication or excessive biological productivity. Eutrophication can lead to dissolved oxygen depletion, the potential for fish kills, and taste-and-odour problems.

Phosphorus occurs in aquatic systems largely as phosphates, in forms that include orthophosphates and organically-bound phosphates, and can be measured as dissolved or particulate phosphorus. These various forms arise from a variety of sources, but may be found naturally leached or from weathering of phosphate-bearing minerals (CCME, 2003; McNeely et al., 1979). Other sources include fertilizers applied in residential or agricultural environments and transported from stormwater or through overland non-point runoff, or may be contributed by sewage/septic discharge of human or agricultural origin (EPA, 2003). Atmospheric and groundwater contributions are other minor sources. Phosphorus concentrations can decline as a result of uptake by aquatic organisms, precipitation, and sedimentation.

At present, the Canadian Water Quality Guidelines have not established a numerical guideline for phosphorus; however, the Alberta Surface Water Quality Guideline is 0.05 mg/L total phosphorus (AENV, 1999).

Total Phosphorus

Total phosphorus (TP) includes both particulate and dissolved forms of this nutrient. It represents the combined form of orthophosphate and organically-bound phosphates.

Elbow River Sites

TP generally increased in concentration along the Elbow River (Figure 13), with median concentrations significantly different among Elbow River sites from 1999 to 2001 ($P<0.05$). In 1999 and 2000, median TP concentrations of 0.004 and 0.005 mg/L at the Weaselhead were significantly higher than all other sites (range of 0.002 to 0.004 mg/L), except Redwood Meadows ($P<0.05$). In 2001, a median TP concentration of 0.004 mg/L at the Weaselhead Bridge was significantly greater than at the Hwy 22 Bridge site (median 0.001 mg/L). In 2002, Elbow River sites upstream from the Glencoe GCC displayed low TP concentrations, with medians from 0.002 to 0.005 mg/L. Concentrations increased in the mid-reaches to a median value of 0.008 mg/L at the Glencoe GCC and to 0.012 mg/L at Sarcee Bridge.

Peak TP concentrations were typically associated with the June/July mountain snowmelt event. In 1999, maximum TP concentrations occurred at Twin Bridges (0.103 mg/L) and the Weaselhead (0.134 mg/L) on July 5 during peak river discharge (Figure 13). In 2000, maximum TP concentrations were recorded at Twin Bridges and the Weaselhead, although the Twin Bridges maximum of 0.077 mg/L occurred on March 27 during the early local snowmelt runoff, whereas the peak concentration at the Weaselhead (0.085 mg/L) occurred in early June. In 2001, the greatest TP concentration was found at Redwood Meadows in early June (0.092 mg/L). Among years, maximum TP concentrations were greatest overall in 2002, with the highest concentrations ranging from 0.005 mg/L at Cobble Flats in mid-May to 0.306 mg/L at Discovery Ridge and 0.668 mg/L at Sarcee Bridge, all occurring during mid-June.

Among all mainstem sites and years the Alberta Surface Water Quality Guideline of 0.05 mg/L was only exceeded in 6% of the samples. The majority of exceedances occurred in 2002, the year of greatest runoff, with exceedance rates of 4% at the Elbow River site above Bragg Creek (2 of 48 samples), increasing to 33% at Sarcee Bridge (6 of 18 samples).

Elbow River Tributary Sites

In all years there were significant differences in TP concentration among tributary sites ($P<0.05$). In 1999, Springbank and Lott Creeks were significantly higher in TP concentration (medians of 0.045 and 0.055 mg/L, Figure 14), than most of the tributaries in the upper reaches (range from 0.002 to 0.023 mg/L) ($P<0.05$). In 2000, medians from 0.034 to 0.076 mg/L at Millburn, Springbank

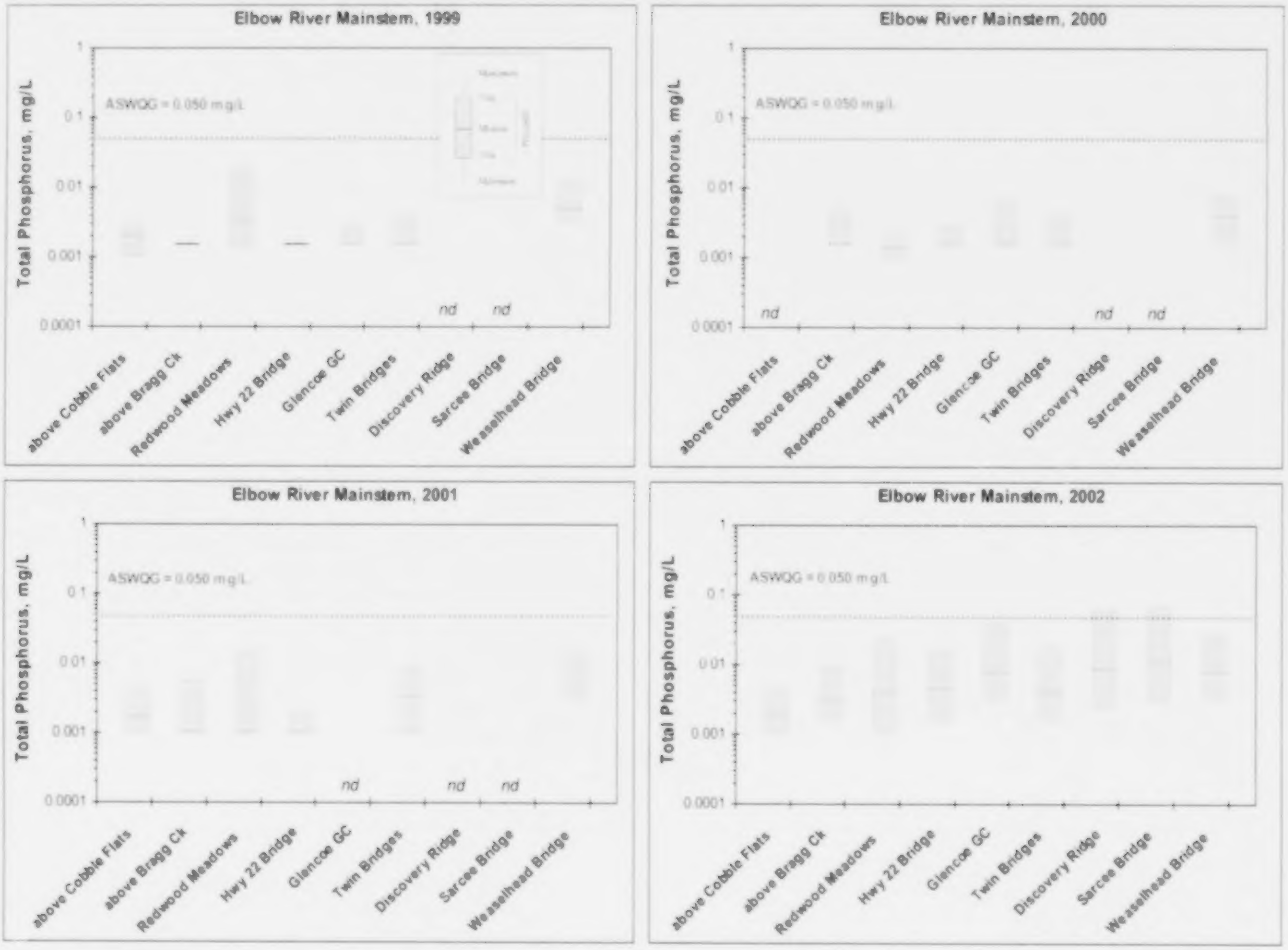
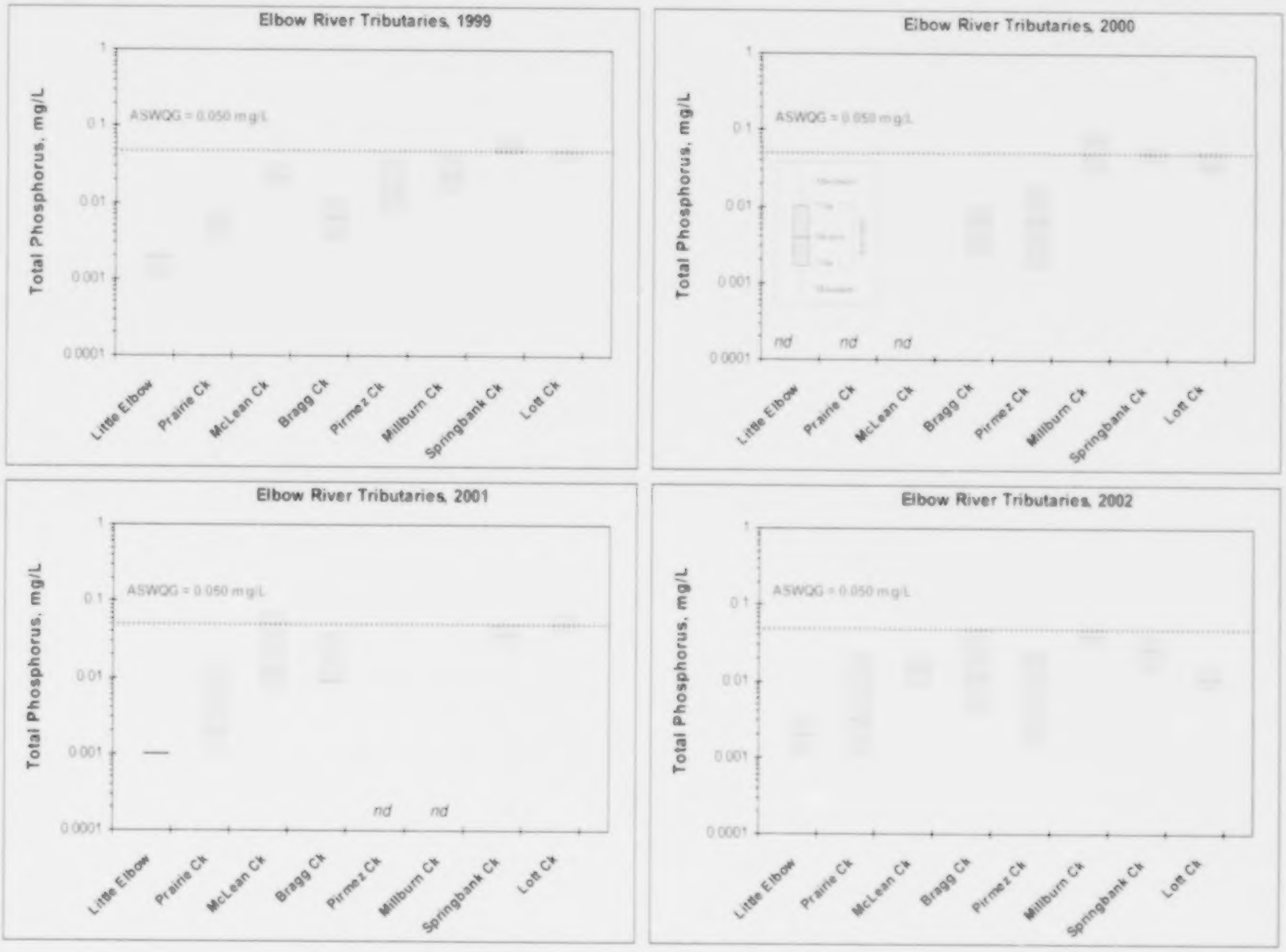


Figure 13. Total phosphorus at Elbow River mainstem sites: March to September, 1999-2002 (*nd=no data*).

and Lott Creeks were significantly greater in concentration than Bragg and Pirmez Creeks, both at 0.007 mg/L (*P*<0.05). In 2001, Lott Creek was significantly greater in TP concentration (0.052 mg/L) than the Little Elbow and Prairie Creeks (*P*<0.05), and in 2002, Millburn Creek was greater in concentration (0.038 mg/L) than all tributaries except McLean and Springbank Creeks (*P*<0.05). In all years sampled, TP concentrations in the Little Elbow River and Prairie Creek were low and varied little, with medians from 0.001 to 0.005 mg/L.

In contrast to the seasonal pattern of TP concentrations in the Elbow River, where peak TP was generally associated with the primary discharge period, the maximum concentrations in tributaries were highly variable through the season, and more likely to peak earlier in the season than the June mountain snowmelt period. Among all tributaries in 1999, 2000 and 2002, the highest TP concentrations were observed in Millburn Creek, with concentrations of 0.780 mg/L, 0.116 mg/L, and 0.167 mg/L, in respective years (Figure 14). However, in 1999 and 2002, peak concentrations at Millburn Creek occurred in mid-April, well before the June/July mountain snowmelt, and in 2000 the maximum occurred in mid-July, after the June runoff.

Exceedance rates of the Alberta Surface Water Quality Guideline of 0.05 mg/L TP ranged from


Elbow River Tributaries, 1999

Elbow River Tributaries, 2000

Elbow River Tributaries, 2001

Elbow River Tributaries, 2002

Figure 14. Total phosphorus at Elbow River tributary sites: March to September, 1999-2002 (*nd=no data*).

lows of 0% in the Little Elbow River, to intermediate rates of 6% to 10% in Prairie Creek, Pirmez Creek and Bragg Creek, to higher rates of 18% in Lott Creek, 21% in McLean Creek, and 34% to 38% in Millburn and Springbank Creeks.

By year, and in contrast to exceedances in the mainstem river, exceedance rates for most tributaries were lower in 2002 than in the lower flow years of 2000 and 2001.

Total Dissolved Phosphorus

Total dissolved phosphorus (TDP) is the fraction of TP which passes through a 0.45 µm filter and is often considered more representative than TP of the fraction which is biologically available to stimulate aquatic plant growth (Bradford and Peters, 1987).

Elbow River Sites

TDP exhibited no apparent longitudinal pattern along the Elbow River in any year (Figure 15). Seasonal medians were consistent among sites and among years, with no significant differences evident ($P>0.05$), and medians ranged from 0.001 to 0.003 mg/L.

Seasonally, TDP concentrations were consistently high early in the season, during either the early spring runoff in March or April, or the primary mountain snowmelt runoff in June, then decreased to low levels often below detection in July through September. In 1999 and 2001, peak concentrations varied little among mainstem sites, ranging from 0.002 in April to 0.026 mg/L in early July (Figure 15). In 2000, the highest concentrations were measured at Twin Bridges and the Weaselhead Bridge, with maximums of 0.054 and 0.044 mg/L, respectively, both associated with the March runoff. In 2002, maximum TDP concentrations ranged from 0.005 mg/L at Cobble Flats to intermediate peaks from 0.020 to 0.033 mg/L at Hwy 22 Bridge and downstream, from late May to early June. The highest TDP measurement for the entire study was 0.062 mg/L at the Elbow River above Bragg Creek in early June 2002.

There are no guidelines for TDP in either the Canadian Water Quality Guidelines or the Alberta Surface Water Quality Guidelines.

Elbow River Tributary Sites

Among tributary sites there was a generally consistent pattern for TDP concentration, with lower levels in tributaries in the upper reaches increasing in concentration to tributaries in the lower reaches (Figure 16), and with statistically significant differences measured in all years ($P<0.05$). In 1999, Springbank Creek with a median concentration of 0.033 mg/L was significantly greater than Bragg, Pirmez, and Millburn Creeks ($P<0.05$), which ranged from 0.002 to 0.012 mg/L. In 2000, significantly greater median TDP concentrations of 0.030 mg/L were measured at both Millburn and Springbank Creeks ($P<0.05$). In 2001, Springbank and Lott Creeks showed significantly greater concentrations at 0.019 mg/L and 0.014 mg/L than the Little Elbow and Prairie Creeks ($P<0.05$). In 2002, the median concentration of 0.022 mg/L in Millburn Creek was significantly higher than all tributaries except McLean and Springbank Creeks ($P<0.05$). Consistently low TDP concentrations were observed in the Little Elbow River and Prairie Creeks in 2001 and 2002, generally at or below the method detection limit (medians of 0.001 to 0.002 mg/L).

Maximum TDP concentration in the tributaries generally followed a pattern similar to peak tributary TP, with maximum values highly variable through the season, but more likely to occur earlier in the season than the June or July mountain snowmelt period. Among all tributaries in all years, the greatest TDP concentrations were observed in either Millburn or Springbank Creeks. Concentrations of 0.140 mg/L and 0.080 mg/L were found in Millburn Creek in 1999 and 2002, and 0.080 mg/L and 0.067 mg/L in Springbank Creek in 2000 and 2001 (Figure 16). In 1999 and 2002, peak concentrations in most tributaries occurred in mid-April, well before the June/July mountain snowmelt. In 2000, the maximum values in Millburn Creek and Springbank Creek occurred in mid-July, after the June runoff.

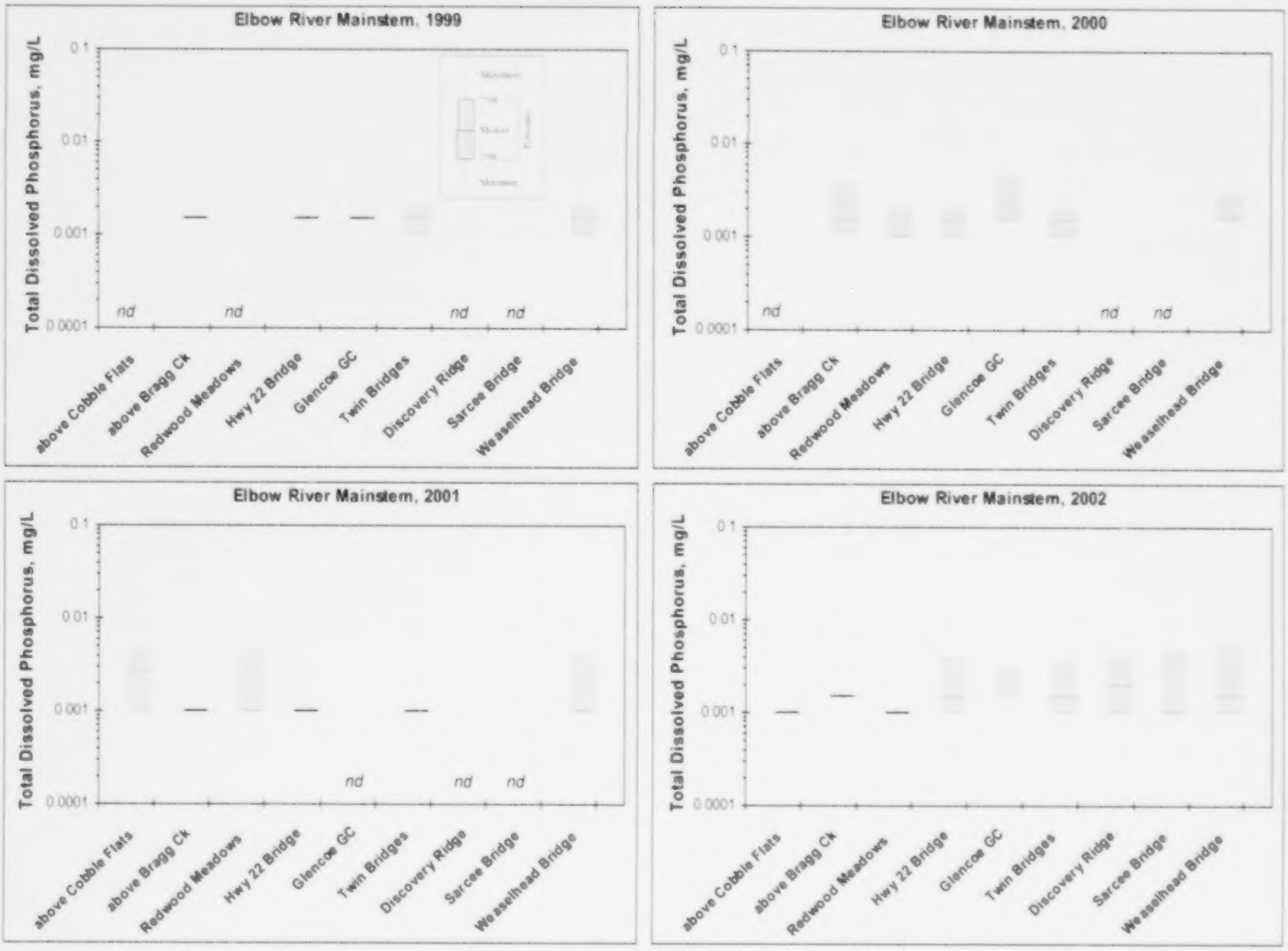


Figure 15. Total dissolved phosphorus at Elbow River mainstem sites: March to September, 1999-2002 (*nd=no data*).

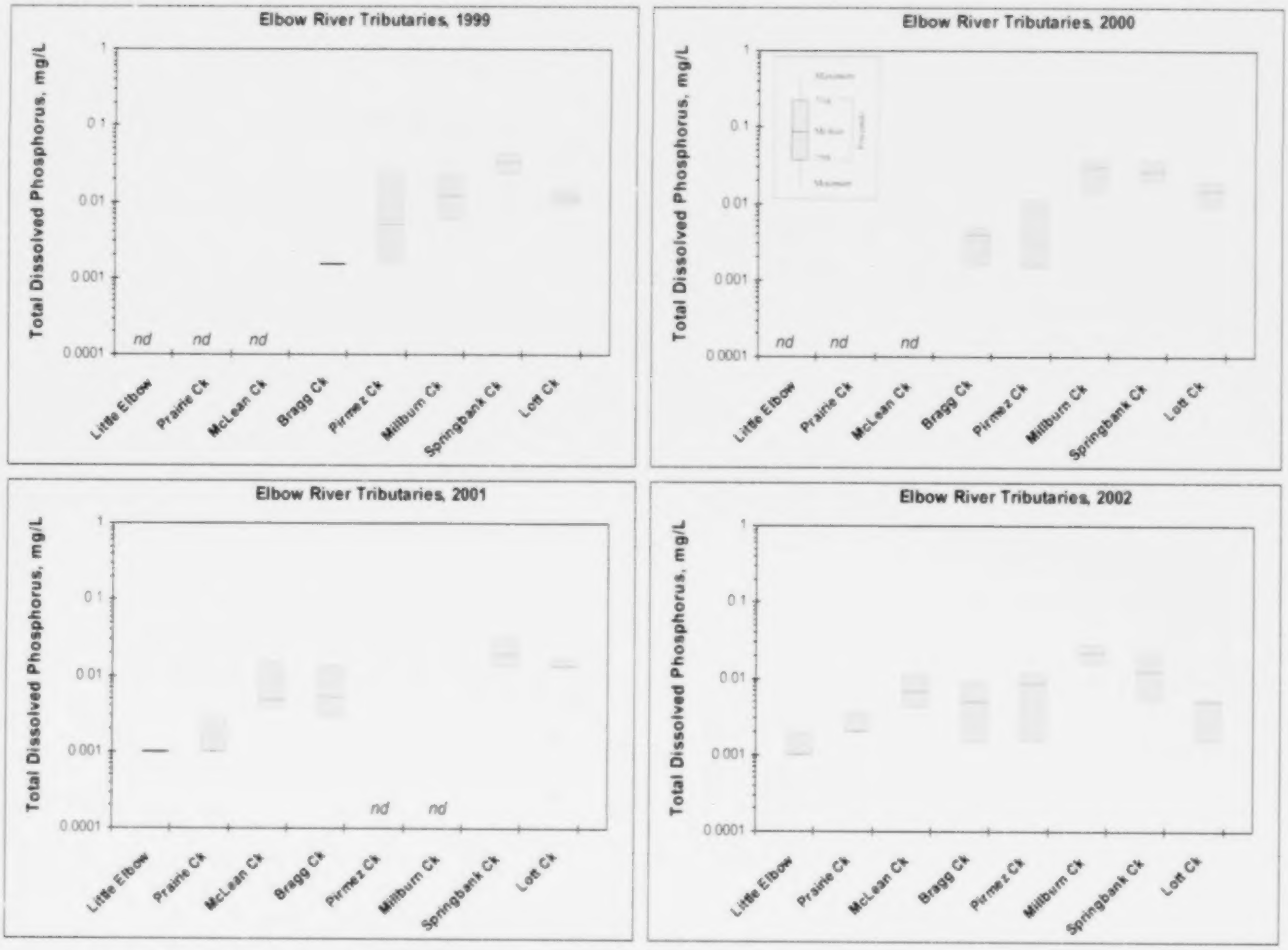


Figure 16. Total dissolved phosphorus at Elbow River tributary sites: March to September, 1999-2002 (*nd=no data*).

Phosphorus Mass Flux

The net mass loading of phosphorus from tributaries and nonpoint sources between Bragg Creek and Weaselhead Bridge was estimated using 1999 phosphorus results (Figure 17). Concentrations were highly variable and it was not possible to calculate acceptable mass estimates for all sites in each reach using 2000 and 2002 data. Factors contributing to high variance in phosphorus measurements could include effects of flow on particulate phosphorus and rapid assimilation and adsorption of dissolved phosphorus. Although a complete accounting of TP mass flux could not be prepared using 2000 and 2002 data, reaches between Elbow River sites with acceptable mass estimates for TP and TDP are presented in Table 5.

In 1999, 454 kg of TP were contributed to the Elbow River by nonpoint sources between the Hamlet of Bragg Creek and the Highway 22 Bridge, while the Bragg Creek tributary alone contributed 62 kg or 14% of the total TP in that reach (Figure 17). Although it is not possible to identify individual sources from the available data, nonpoint sources appeared to be contributing TP far greater than tributary loadings to this reach in the spring of 1999. The influx of TP from nonpoint sources between Bragg Creek and Highway 22 in 1999 could reflect contributions from the Hamlet of Bragg Creek, Redwood Meadows, agriculture, and loading from other smaller tributaries and sources in this reach. It is important to note that the automated samplers were removed before the peak spring flood in 1999. Accordingly, the flux estimates do not include the period of highest flows, and likely missed significant TP loading during this time period.

No such influx of TP below the Hamlet of Bragg Creek from nonpoint sources was evident in the mass loading calculations for the same reach in 2000, perhaps because Elbow River flows were much below average that year (Figure 2). Presumably, most tributary flows were also lower than average in 2000, however, there is no long-term flow gauging on these tributaries. Yet, peak flows for all the sampled tributaries from Bragg Creek to Weaselhead Bridge, except for Springbank Creek, were generally lower in 2000 than in 2002 (Table 4). Less precipitation would also cause less movement of TP from adjacent land, and could influence groundwater movement into the river. An accurate estimate of TP mass loading could not be calculated for the reach between Bragg Creek and Highway 22 from the 2002 data.

TP concentrations increased moderately between the Elbow River site above Bragg Creek and Highway 22 Bridge in 2002, but there was no statistically significant difference in either TP or TDP concentrations between these sites in 1999, 2000, or 2002. Accordingly, there was no

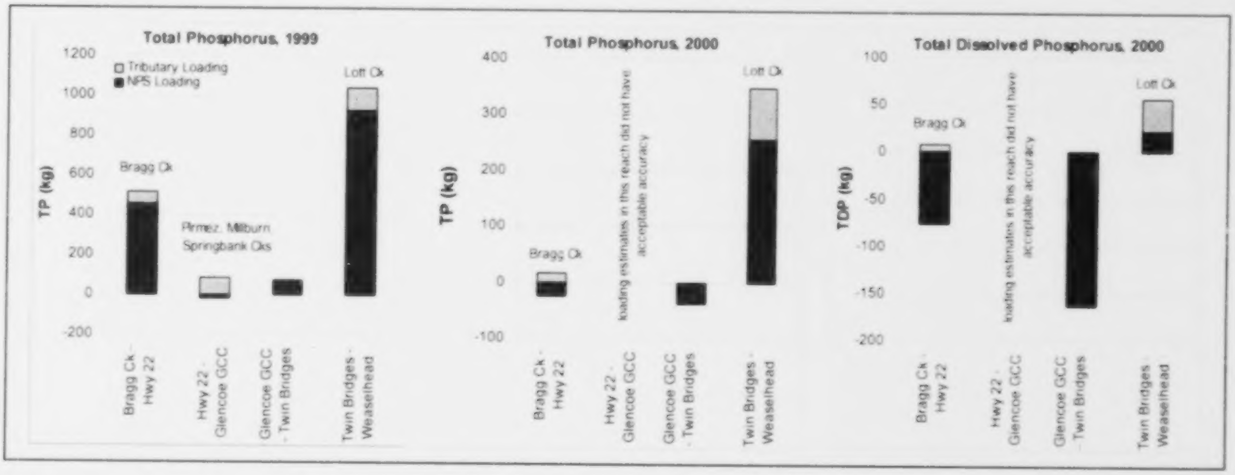


Figure 17. Mass flux of total phosphorus and total dissolved phosphorus (kg per sampling season) from tributaries and non-point sources for Elbow River reaches: April 7 to July 8, 1999; May 1 to August 1, 2000.

Table 5. Mass flux for total phosphorus and total dissolved phosphorus (kg per sampling season, coefficients of variation in parentheses) for the Elbow River and its major tributaries between Bragg Creek and Weaselhead Bridge. Less reliable estimates (CV >0.2) are in bold italics.

	Total Phosphorus, kg			Total Dissolved Phosphorus, kg		
Sites	**1999**	**2000**	**2002**	**1999**	**2000**	**2002**
Elbow River						
Above Bragg Creek	577 (0.169)	259 (0.122)	***2,408 (0.275)***	108 (0.0)	234 (0.139)	***766 (0.587)***
Redwood Meadows	***1,195 (0.397)***	***196 (0.308)***	***1,182 (0.262)***			***1,182 (0.262)***
Highway 22 Bridge	1,094 (0.155)	251 (0.186)	***8,711 (0.287)***	***189 (0.473)***	166 (0.165)	741 (0.190)
Glencoe GCC	1,159 (0.154)	455 (0.141)	18,099 (0.172)	104 (0.0)	287 (0.151)	***543 (0.282)***
Twin Bridges	1,229 (0.164)	418 (0.162)	***24,877 (0.201)***	***174 (0.370)***	123 (0.134)	***1042 (0.207)***
Sarcee Bridge			35,544 (0.053)			1,759 (0.150)
Weaselhead Bridge	2,269 (0.083)	766 (0.194)	***7,813 (0.248)***	***234 (0.369)***	179 (0.170)	1,116 (0.158)
Elbow River Tributaries						
Bragg Creek	62 (0.171)	16 (0.137)	309 (0.121)	10 (0.055)	8 (0.157)	***56 (0.209)***
Pirmez Creek	43 (0.110)	***80 (0.228)***	71 (0.056)	26 (0.105)	***40 (0.303)***	38 (0.052)
Millburn Creek	30 (0.178)	28 (0.062)	16 (0.188)	12 (0.157)	12 (0.091)	9 (0.178)
Springbank Creek	12 (0.096)	5 (0.080)	2 (0.087)	7 (0.158)	3 (0.112)	1 (0.104)
Lott Creek	110 (0.070)	94 (0.119)	38 (0.093)	26 (0.107)	34 (0.128)	15 (0.111)

Sarcee Bridge not sampled in 1999 and 2000

evidence that the Hamlet of Bragg Creek or other sources between these two sites significantly affected phosphorus concentrations in this reach of the Elbow River during these sampling periods.

During sampling in both 1999 and 2000, a much greater mass of TP from nonpoint sources (930 and 255 kg respectively) entered the Elbow River between Twin Bridges and Weaselhead Bridge, than from any other source or tributary to the Elbow River (Figure 17, Table 5). A very large influx of TP from nonpoint sources also occurred in this lower reach near Calgary in 2002. The 2002 estimate of TP mass for the Elbow River at Sarcee Bridge was 35,543 kg, an amount 17,445 kg greater or almost double the estimate for the Elbow River at the Glencoe GCC.

It was not possible to estimate mass accurately at all the Elbow River sampling sites in 2002. Very high flows caused extremely broad variance in the TP data in 2002. Furthermore, it is not possible to assess the relative importance of individual TP sources between Twin Bridges and Weaselhead Bridge from the available data. These sources could include runoff from new subdivisions, agricultural surface runoff that enters the north channel of the river and empties downstream of Twin Bridges, and three storm sewers that discharge to this reach, namely G19, G20, and the 69th St. retention pond. Significant bank erosion was also identified at various locations during the aerial survey (Maps 1 to 3 at end of report). This erosion and resuspension of bed material could contribute particulate phosphorus, which is often a large part of TP mass. TDP mass was only 4.9 to 29.5% of TP mass estimates in this reach during 2000 and 2002; the remainder (≥70%) was particulate phosphorus.

TP and TDP median concentrations were higher in tributary streams than in the Elbow River,

Table 5. Mass flux for total phosphorus and total dissolved phosphorus (kg per sampling season, coefficients of variation in parentheses) for the Elbow River and its major tributaries between Bragg Creek and Weaselhead Bridge. Less reliable estimates (CV >0.2) are in bold italics.

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TP and TDP median concentrations were higher in tributary streams than in the Elbow River, sometimes well over the ASWQ guideline of 0.05 mg/L (Figures 14 and 16). Median concentrations in Pirmez, Millburn, Springbank, and Lott Creek were also at times greater than concentrations associated with nuisance periphyton biomass in the Bow River (TP: 18 µg/L, TDP: 6.4 µg/L; Sosiak, 2002). Lott Creek contributed a greater mass of both total and dissolved phosphorus than any other tributary stream in 1999 and 2000, when flows were relatively low at most sites. The mass of TP contributed by Bragg Creek was far greater than any other stream in 2002, when Elbow River flows were well above average (Figure 2). Where this could be assessed, the total mass of TP contributed by nonpoint sources was greater than the contribution from tributaries. In contrast, Lott Creek contributed a greater mass of TDP to the Elbow River than nonpoint sources in the same reach in 2000 (Figure 17).

Like TP, the mass of TDP increased greatly between Highway 22 and Weaselhead Bridge in 2002. The TDP mass at Weaselhead Bridge that year was 1116 kg, which was an increase of 375 kg or an amount 51% greater than the mass at Highway 22 (Table 5). However, no such spatial trend in TDP mass was apparent in 2000, when drier conditions prevailed, or 1999 when the spring flood was missed. TDP in those years was close to the detection limit except at Weaselhead Bridge. TDP is highly reactive, and the mass of TDP entering the river may be rapidly assimilated under the lower flows (< 20 m^3/s, Figure 2) that occurred in 1999 and 2000.

Phosphorus Temporal Trends

A small but significant increase in TDP concentrations occurred over time at both Twin Bridges and Weaselhead Bridge (Table 6). Although the rate of change at these locations has been too small to accurately quantify, TDP trends were statistically significant and increasing levels are apparent in plots of concentration (Figure 18). Since there were sufficient years of TDP data available for both sites (1988-2002), the trends appear to be real and indicate that increased TDP loading is occurring between the Glencoe GCC and Weaselhead Bridge. A similar trend was identified in previous trend analysis on a shorter dataset from Twin Bridges (Sosiak, 1999).

River flow could be contributing to changes in TDP concentration. Flows in the upper Elbow River were below average during May to July 1988 and 1989 (Beers and Sosiak, 1993). Lower flows could have contributed to lower TDP concentrations at these two sampling locations during those years, but should have similarly affected various other Elbow River sites, which did not exhibit significant trends in phosphorus concentrations. Similarly, declining levels of particulate phosphorus during the recent years of below average flow could explain the declining TP trends found at various sites (Table 6).

Table 6. Significant monotonic trends for total and total dissolved phosphorus in the Elbow River and its major tributaries.

		Sen Slope (units/yr) for significant trends (seasonal kendall tau test, except as indicated[a])	
Sites	Time Period/ (yrs of data)	Total Phosphorus µg/L	Total Dissolved Phosphorus µg/L
Elbow River Mainstem			
Cobble Flats	1988-2002 (4, 4)	NS[a]	NS[a]
Above Bragg Creek	1989-2002 (4, 4)	NS	NS
Highway 22 Bridge	1980-2002 (7, 7)	**-1.0**[a]	NS
Glencoe GCC	1988-2002 (8, 7)	NS[a]	NS[a]
Twin Bridges	1982-2002 (15, 11)	NS	**+<0.01**[b]
Weaselhead Bridge	1988-2002 (15, 13)	**-3.4**	**+<0.01**[a]
Upper Glenmore Reservoir	1982-2002 (14, 10)	**-0.2**	NS[a, c]
Glenmore Raw Intake	1989-2002 (0, 0)	-	
Elbow River at 9th Ave.	1982-2002 (13, 12)	**-3.0**	**-0.1**[a]
Elbow River Tributaries			
Little Elbow River	1978-2002 (6, 3)	NS[a]	
McLean Creek	1988-2002 (7, 4)	NS	NS[a]
Bragg Creek	1988-2002 (6, 6)	NS[a]	NS[a]
Pirmez Creek	1989-2002 (4, 4)	NS	NS
Millburn Creek	1989-2002 (4, 4)	NS	NS
Springbank Creek	1989-2002 (3, 3)	-	
Lott Creek	1988-2002 (6, 6)	NS[a]	**-0.3**

[a] Kendall tau test (non-seasonal); [b] sampled 1988-2002; [c] sampled 1993-2002; NS = no statistically significant trend detected; hyphen indicates insufficient historical data for trend analysis (N < 4 yrs).

The exact source of increased TDP in the reach between the Glencoe GCC and Weaselhead Bridge cannot be identified from the available data, but potential sources could include the same ones identified for TP, namely urban areas, agriculture, and groundwater contributions. TDP is typically highest in areas of high agricultural intensity in Alberta (Anderson et al., 1998). Since there has been no evidence of increasing TDP concentration in tributaries (Table 6), where these could be tested, it seems unlikely that tributary impacts can account for the increase in TDP concentration in this reach.

The only significant change in TDP concentration that was detected at a tributary site was a decline in Lott Creek. This decline was based on just five years of sampling, most in recent years, and may be unduly influenced by the recent years of below average flow. Land use has changed over time in the Lott Creek basin, as the basin has been developed for low-density residential use (including several small lakes), a golf course, and a recreational vehicle park. Some grazing of cattle and horses, and additional small, aquaculture operations previously occurred in the basin. These changes in land use could

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Highway 22 Bridge	1980-2002 (7, 7)	**-1.0**[a]	NS
Glencoe GCC	1988-2002 (8, 7)	NS[a]	NS[a]
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Weaselhead Bridge	1988-2002 (15, 13)	**-3.4**	**+<0.01**[a]
Upper Glenmore Reservoir	1982-2002 (14, 10)	**-0.2**	NS[a, c]
Glenmore Raw Intake	1989-2002 (0, 0)	-	-
Elbow River at 9th Ave.	1982-2002 (13, 12)	**-3.0**	**-0.1**[a]
Elbow River Tributaries			
Little Elbow River	1978-2002 (6, 3)	NS[a]	-
McLean Creek	1988-2002 (7, 4)	NS	NS[a]
Bragg Creek	1988-2002 (6, 6)	NS[a]	NS[a]
Pirmez Creek	1989-2002 (4, 4)	NS	NS
Millburn Creek	1989-2002 (4, 4)	NS	NS
Springbank Creek	1989-2002 (3, 3)	-	-
Lott Creek	1988-2002 (6, 6)	NS[a]	**-0.3**

[a] Kendall tau test (non-seasonal); [b] sampled 1988-2002; [c] sampled 1993-2002. NS = no statistically significant trend detected; hyphen indicates insufficient historical data for trend analysis (N < 4 yrs).

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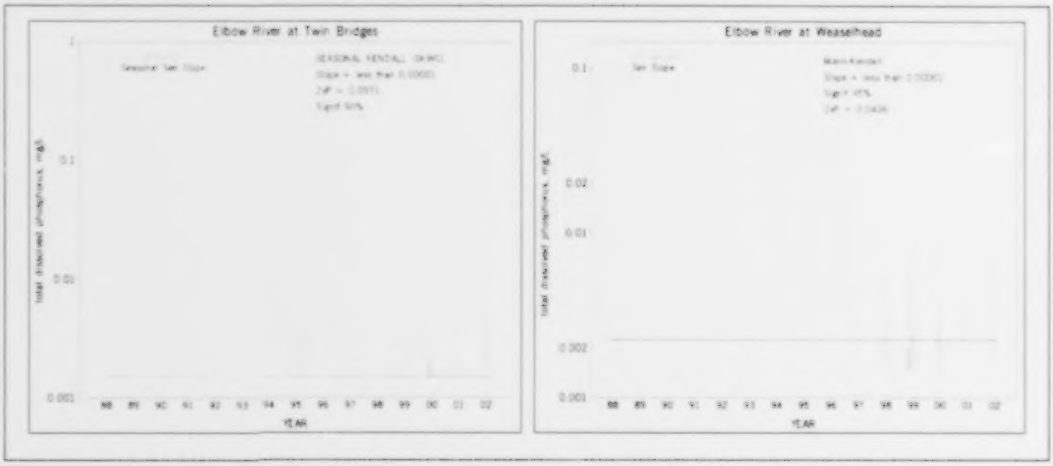

Figure 18. Total dissolved phosphorus in the Elbow River at Twin Bridges and the Weaselhead Bridge, 1988-2002.

have contributed to declining TDP concentrations. Aside from increasing total coliform counts, which will be discussed later, no other trends in water quality variables were detected for the Lott Creek basin.

Nitrogen

Nitrogen, along with phosphorus, is an important nutrient and a potential contributor to eutrophication in aquatic systems. Cycling of nitrogen in ecosystems is complex, affected by both biotic and abiotic processes. Some bacteria, such as cyanobacteria, can assimilate or fix atmospheric nitrogen, converting it to ammonia and, under appropriate conditions, to nitrite and nitrate. Mineralization of organic nitrogen by microbial decomposition forms another pathway in the nitrogen cycle leading to the production of ammonia.

Nitrate and ammonia may be washed from the atmosphere by precipitation and transported to the soil or surface water, with sources which can include volatilization from disturbed vegetation or soil, products of combustion from transportation sources, power generation or industrial inputs (McNeely et al., 1979). Nitrate may be weathered from geological deposits of nitrate salts.

Nitrogen can be delivered to surface waters through runoff, erosion and subsurface flow, with nitrate the form most susceptible to leaching to the groundwater. Inorganic fertilizers and manure applied to cropland are the most common sources of nitrate to groundwater, particularly when application rates exceed plant nutrient needs (EPA, 2003). Nitrite and organic nitrogen are unstable in aerated waters and are generally considered to be more indicative of pollution from disposal of sewage or organic wastes (Hem, 1989). Nitrite, nitrate, ammonia, and TKN are often high in wastewater. Nitrite is typically low in surface waters, except below discharge points for wastewater treatment plants, and nitrate+nitrite is typically highest in streams in areas of high agricultural intensity in Alberta (Anderson et al., 1998).

Canadian Water Quality Guidelines specify a numerical limit for nitrate+nitrite nitrogen of 10 mg/L for drinking water based on health concerns related to infantile methemoglobinemia (CCME, 2003). For the protection of aquatic life, CCME (2003) specifies a guideline of 13 mg/L as nitrate ion (i.e., 2.9 mg/L as N). The Alberta Surface Water Quality Guideline for nitrate+nitrite is 100 mg/L for waters considered for agricultural uses (AENV, 1999).

For the protection of freshwater aquatic life, Canadian Water Quality Guidelines specify a range of total ammonia guidelines at 10 °C: 1.04 mg/L at pH 8 to 32.4 mg/L at pH 6.5 (CCME 2001, cited in CCME, 2003). The Alberta Surface Water Quality Guideline for TN is 1 mg/L for the protection of freshwater life (AENV, 1999).

Nitrate+Nitrite Nitrogen

Nitrate is the principal and most stable form of inorganic nitrogen in aquatic systems. It is highly soluble and readily transported atmospherically, and in both surface and subsurface flows. Nitrite is an intermediate form in the nitrification/denitrification pathway, usually found in negligible quantities because of its instability in the presence of oxygen (McNeely et al., 1979). Because of the unstable nature of nitrite, nitrate and nitrite are often reported as a combined variable.

Elbow River Sites

Among all years, there were significant differences in nitrate+nitrite concentrations among mainstem sites ($P<0.05$). Concentrations were generally lower at sites further downstream (Figure 19). Medians decreased substantially from the upper sites at Cobble Flats, with medians of 0.112 in 1999 and 0.119 mg/L in 2001, significantly greater than all downstream sites in 1999 and the Weaselhead alone in 2001 ($P<0.05$). Median concentrations in the Elbow River above Bragg Creek were significantly greater than at the Glencoe GCC in 1999, Twin Bridges in 1999 and 2000, Weaselhead in 2000, and Sarcee Bridge in 2002 ($P<0.05$).

While nitrate+nitrite concentrations generally decreased from the headwaters along the Elbow River, there were two reaches in which medians increased or remained relatively constant (Figure 19). Medians increased by 0.029 mg/L from 0.077 to 0.106 mg/L from Redwood Meadows to the Glencoe GCC in 2002. In the lower study reach from Twin Bridges to the Weaselhead this variable increased by 0.005 mg/L to 0.015 mg/L in both 1999 and 2000. In 2001 and 2002 median nitrate+nitrite concentrations decreased by 0.003 mg/L and 0.006 mg/L, respectively between these two sites.

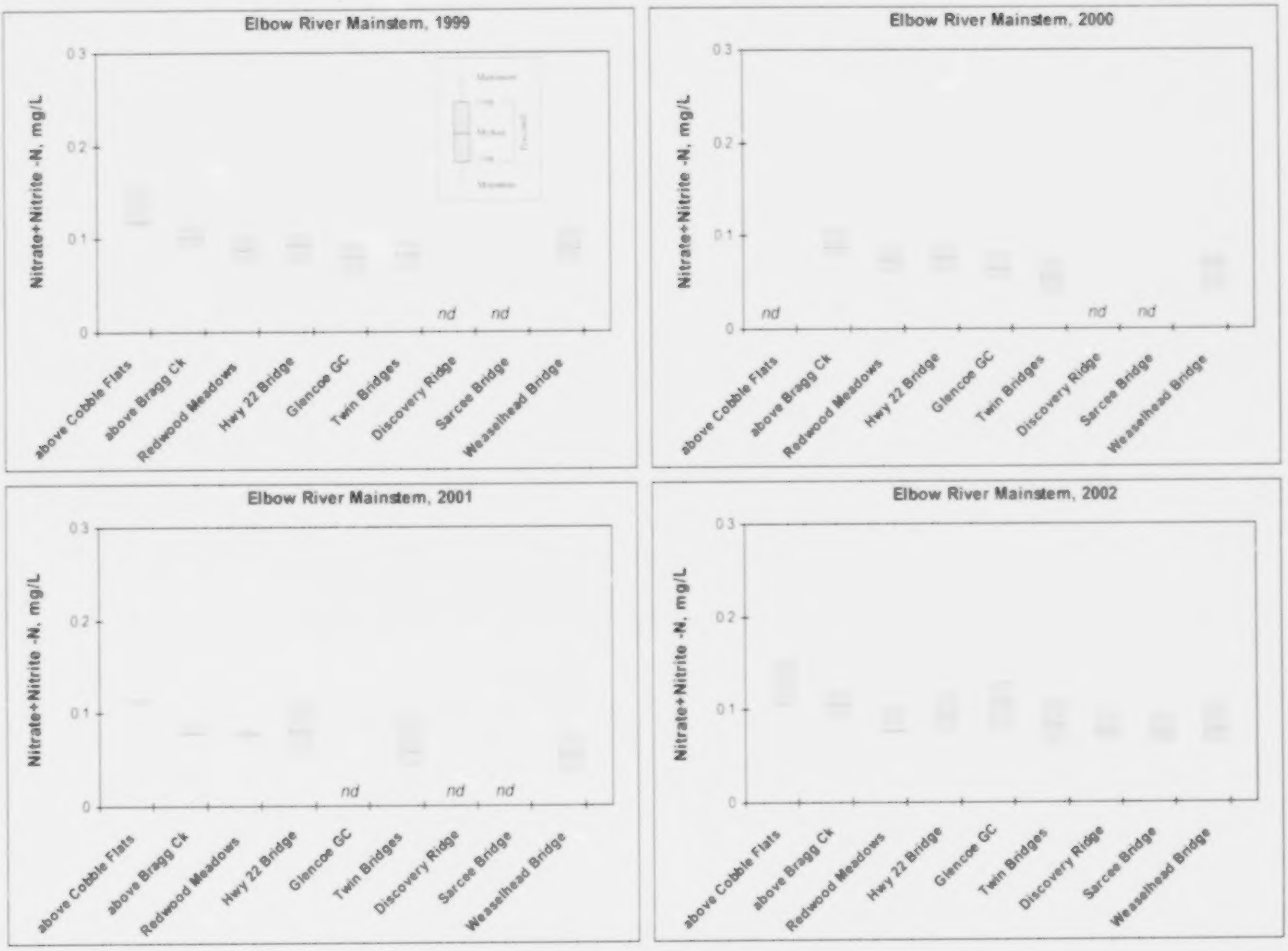

Figure 19. Nitrate+nitrite nitrogen at Elbow River mainstem sites: March to September, 1999-2002 (*nd=no data*).

Although median concentrations were lowest at the Weaselhead Bridge site in three of the four years, the highest nitrate+nitrite concentrations were recorded at this site in 1999 to 2001 (Figure 19). In those years, maximum values from 0.163 mg/L to 0.179 mg/L occurred in early to mid-May in 1999 and 2000, and early June in 2001, all prior to spring runoff for the respective years. Seasonal minimum concentrations varied among sites and over time. The lowest concentrations found were 0.002 mg/L at both the Elbow River above Bragg Creek in mid-May 2000, and the Glencoe GCC in early August 2002.

Elbow River Tributary Sites

There was no consistent longitudinal pattern of nitrate+nitrite concentration among Elbow River tributaries (Figure 20), although spatially, three clusters of tributaries could be discerned based on concentration: (1) tributaries with very low nitrate+nitrite concentrations, which included Prairie Creek (median range: 0.005 to 0.011 mg/L) and Millburn Creek (medians of 0.002 mg/L); (2) sites with moderate concentrations, as found in the Little Elbow (median range: 0.119 to 0131 mg/L), Springbank Creek (0.027 to 0.092 mg/L) and Lott Creek (0.087 to 0.115 mg/L); and (3) Pirmez Creek, which consistently had the highest concentrations (median range: 0.128 to 0.447 mg/L).

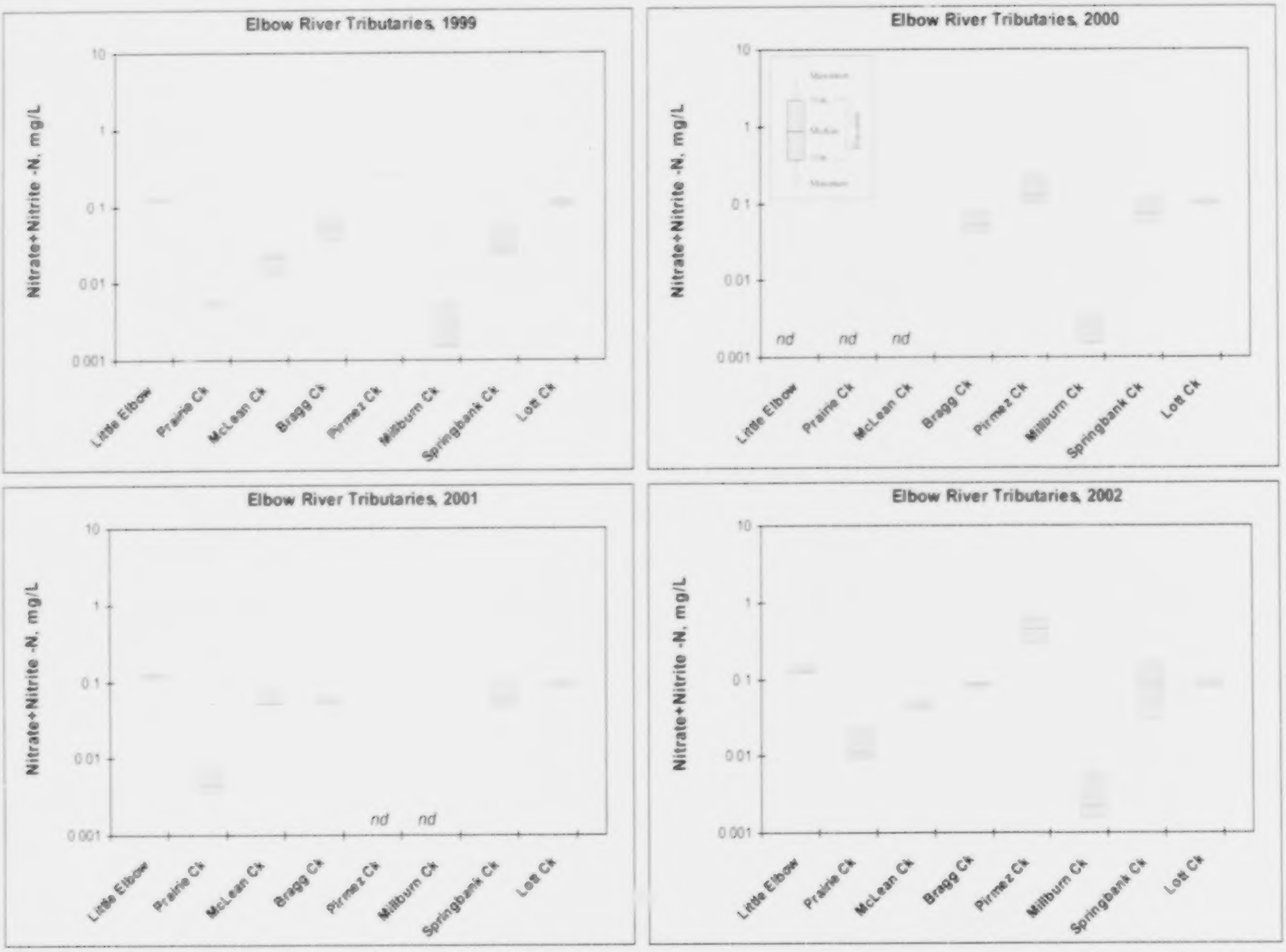

Figure 20. Nitrate+nitrite nitrogen at Elbow River tributary sites: March to September, 1999-2002 (*nd=no data*).

Moreover, these groups were statistically distinct, as in all years there were significant differences in nitrate+nitrite concentrations among sites ($P<0.05$). Pirmez Creek nitrate+nitrite concentrations were significantly greater than all sites in 1999 and 2002 ($P<0.05$), and greater than concentrations in Bragg, Millburn and Springbank Creeks in 2000 ($P<0.05$). By contrast, Prairie and Millburn Creek nitrate+nitrite concentrations were both significantly less than Bragg, Pirmez, Springbank and Lott Creeks in 1999 and 2002 ($P<0.05$), and Millburn Creek was significantly less than all other sites in 2000 ($P<0.05$). Nitrate+nitrite concentrations in Prairie Creek alone were less than Little Elbow, Springbank and Lott Creeks in 2001 ($P<0.05$).

Seasonally, nitrate+nitrite concentrations were generally higher in the early part of the sampling season, decreased during July and August, and increased again in September. In 1999, peak nitrate+nitrite concentrations at Springbank Creek (0.379 mg/L) and Bragg Creek (0.208 mg/L) occurred in April, whereas the maximum Lott Creek measurement (0.307 mg/L) occurred in September (Figure 20). In Pirmez Creek, maximum nitrate+nitrite concentrations were variable among years, with peaks of 0.291 mg/L in early June 1999, 0.301 mg/L in mid-May 2000, and 1.030 mg/L in late June 2002.

Nitrate+Nitrite Nitrogen Mass Flux

The net mass of nitrate+nitrite declined along the Elbow River except between Twin Bridges and Weaselhead, where the mass increased in 1999 and 2002 (Figure 21, Table 7) presumably due to nonpoint sources close to Calgary and loadings from Lott Creek. Nonpoint sources in this reach could include loadings from urban runoff contributed by storm sewers, agriculture, and contributions from groundwater. No such influx of nitrate+nitrite occurred between Twin Bridges and Weaselhead in 2000, perhaps because of less precipitation and runoff that year. The decline in nitrate+nitrite concentration and mass along the Elbow River is likely a result of uptake by aquatic plants, and some bacterial breakdown (denitrification).

Table 7. Mass flux for nitrate+nitrite nitrogen (kg per sampling season, coefficients of variation in parentheses) for the Elbow River and its major tributaries between Bragg Creek and Weaselhead Bridge. Less reliable estimates (CV >0.2) are in bold italics.

	Nitrate+Nitrite Nitrogen, kg		
Sites	**1999**	**2000**	**2002**
Elbow River			
Above Bragg Creek	7,326 (0.023)	6,998 (0.092)	22,740 (0.052)
Redwood Meadows	-	-	-
Highway 22 Bridge	7,093 (0.030)	5,250 (0.056)	21,355 (0.043)
Glencoe GCC	5,866 (0.046)	4,401 (0.044)	23,991 (0.070)
Twin Bridges	5,623 (0.042)	4,645 (0.043)	19,945 (0.060)
Sarcee Bridge			21,349 (0.049)
Weaselhead Bridge	6,729 (0.059)	4,492 (0.066)	22,527 (0.050)
Elbow River Tributaries			
Bragg Creek	105 (0.082)	88 (0.090)	438 (0.058)
Pirmez Creek	995 (0.022)	785 (0.054)	2,544 (0.077)
Millburn Creek	***5 (0.339)***	2 (0.146)	***8 (0.580)***
Springbank Creek	***7 (0.361)***	7 (0.122)	5 (0.146)
Lott Creek	306 (0.037)	231 (0.050)	336 (0.059)

Sarcee Bridge not sampled in 1999 and 2000; hyphen indicates insufficient data to prepare mass flux estimate.

Tributaries between Highway 22 and the Glencoe GCC were major sources of nitrate+nitrite in 1999 and 2000 (Figure 21, Table 7), in particular Pirmez Creek, which contributed a substantial mass of nitrate+nitrite each year, appreciably greater than any

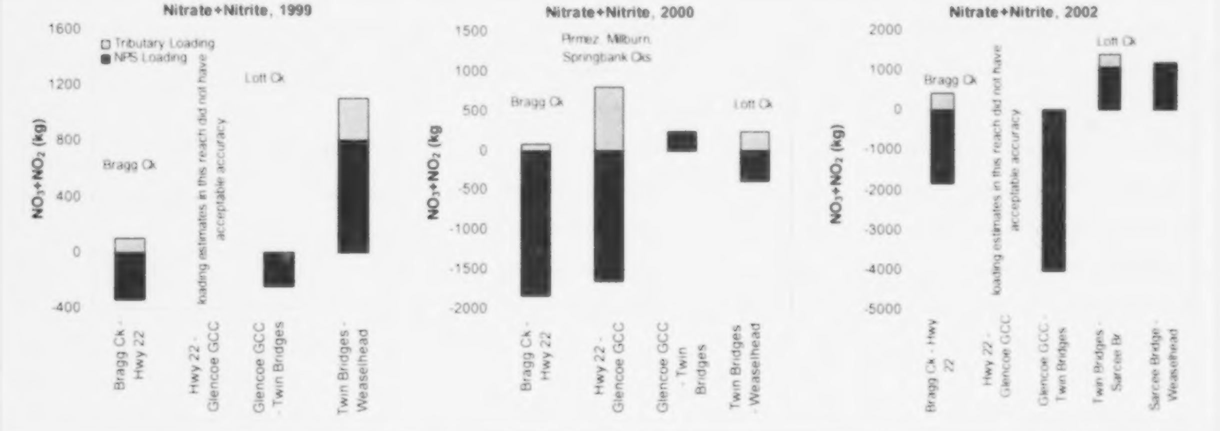

Figure 21. Mass flux of nitrate+nitrite (kg per sampling season) from tributaries and non-point sources for Elbow River reaches: April 7 to July 8, 1999; May 1 to August 1, 2000; April 15 to August 1, 2002.

Nitrate+Nitrite Nitrogen Mass Flux

The net mass of nitrate+nitrite declined along the Elbow River except between Twin Bridges and Weaselhead, where the mass increased in 1999 and 2002 (Figure 21, Table 7) presumably due to nonpoint sources close to Calgary and loadings from Lott Creek. Nonpoint sources in this reach could include loadings from urban runoff contributed by storm sewers, agriculture, and contributions from groundwater. No such influx of nitrate+nitrite occurred between Twin Bridges and Weaselhead in 2000, perhaps because of less precipitation and runoff that year. The decline in nitrate+nitrite concentration and mass along the Elbow River is likely a result of uptake by aquatic plants, and some bacterial breakdown (denitrification).

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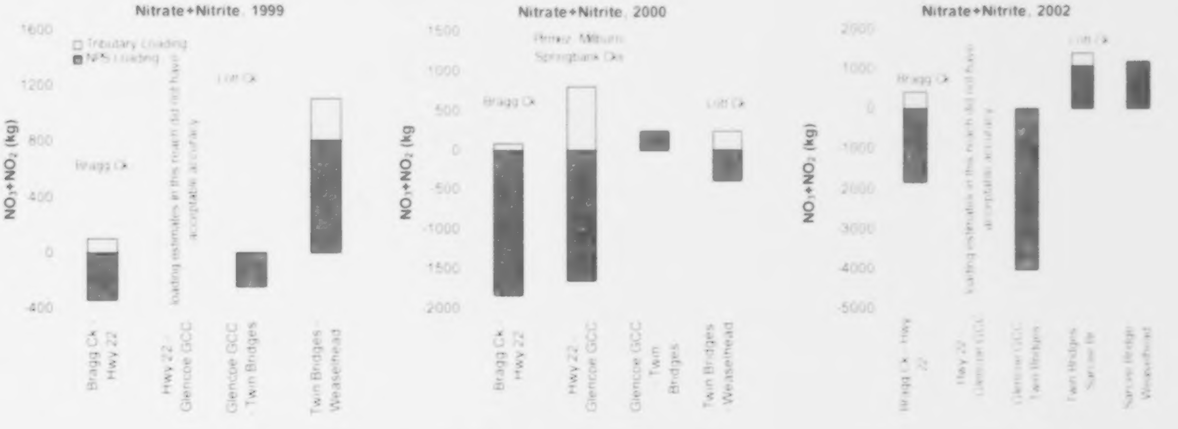

Figure 21. Mass flux of nitrate+nitrite (kg per sampling season) from tributaries and non-point sources for Elbow River reaches: April 7 to July 8, 1999; May 1 to August 1, 2000; April 15 to August 1, 2002.

other tributary. In fact, of the total mass loading of nitrate+nitrite through this reach in 2002 (2636 kg), 2544 kg or 97% was attributable to contributions from Pirmez Creek.

All nitrate+nitrite measurements at all sites were well below all numerical Canadian water quality guidelines for this variable (CCME, 2003). Yet, the CCME (2003) also states that "concentrations that stimulate weed growth should be avoided." Median nitrate+nitrite in Pirmez Creek in 2002 was greater than the concentration that was associated with nuisance periphyton biomass in the Bow River (0.267 mg/L; Sosiak, 2002), but just below this critical concentration in 1999 and 2000. Accordingly, nitrate+nitrite concentrations in Pirmez Creek could be associated with nuisance growths of periphyton some years, although there is no reason to expect excessive growth of periphyton due to this variable at other sampling locations in the Elbow basin. No actual periphyton biomass measurements are available for Pirmez Creek.

Nitrate+Nitrite Nitrogen Temporal Trends

In spite of the net loss in nitrate+nitrite at various locations along the Elbow River in these sampling years, a significant increasing trend in nitrate+nitrite concentration occurred at almost all upper Elbow River sites during sampling from 1979 to 2002 (Table 8), except for an upstream reference site at Cobble Flats, above which there are fewer human impacts. An increasing trend was also found in Bragg Creek near the mouth. These results suggest either atmospheric deposition of nitrate+nitrite, or an anthropogenic surface source. A significant increase in this variable also occurred in the Little Elbow River near the mouth (Figure 22, Table 8). The south-west corner of a grazing allotment is upstream from this site, and commercial trail riding also occurs upstream. Although there were only five years of nitrate+nitrite data at this site, the upward trend in concentration remains clear.

Table 8. Significant monotonic trends for nitrate+nitrite nitrogen in the Elbow River and its major tributaries.

		Sen Slope (units/yr) for significant trends (seasonal kendall tau test, except as indicated[a])
Sites	Time Period/ (yrs of data)	Nitrate+ Nitrite Nitrogen, µg/L
Elbow River Mainstem		
Cobble Flats	1988-2002 (4)	NS[a]
Above Bragg Creek	1979-2002 (5)	**+1.7**
Highway 22 Bridge	1979-2002 (7)	**+1.6**
Glencoe GCC	1979-2002 (8)	**+2.3**
Twin Bridges	1979-2002 (8)	**+1.4**
Weaselhead Bridge	1988-2002 (11)	**+1.9**
Upper Glenmore Reservoir	1982-2002 (13)	NS
Glenmore Raw Intake	1989-2002 (0,0)	-
Elbow River at 9th Ave.	1974-2002 (13)	NS
Elbow River Tributaries		
Little Elbow River	1978-2002 (6)	**+2.3**
McLean Creek	1978-2002 (7)	NS
Bragg Creek	1988-2002 (6)	**+3.6**
Pirmez Creek	1990-2002 (3)	-
Millburn Creek	1990-2002 (3)	-
Springbank Creek	1989-2002 (3)	-
Lott Creek	1988-2002 (6)	NS[a]

[a] Kendall tau test (non-seasonal); NS = no statistically significant trend detected; hyphen indicates insufficient historical data for trend analysis (N < 4 yrs).

No significant trends in flow were found at Twin Bridges over the period of record. Therefore, changes in dilution of groundwater seem unlikely to account for the increasing trends in Elbow River nitrate+nitrite. However, impacts of groundwater cannot be discounted for mainstem and tributary sites. To evaluate whether dilution of nitrate+nitrite from groundwater is a factor, flow trends in tributary streams would have to be assessed. However, these stream sites do not have daily flow gauging over the historic sampling period (e.g., 1978-2002 for Little Elbow River). Furthermore, it is not known whether groundwater nitrate+nitrite has increased over time, and may be impacting river concentrations.

Consequently, the reasons for these increasing trends in nitrate+nitrite in the Elbow River basin are not known. However, an increasing trend in nitrate+nitrite was also found at all sites on the Bow River from a relatively pristine site upstream from Lake Louise, to a site upstream from downtown Calgary at Bowness (Sosiak, 2002). This suggests that this pattern in the Elbow watershed may be of broader scale, possibly attributable to long-range transport. Further work is needed to determine the reason for this trend in nitrate+nitrite concentration.

Nitrate+Nitrite Nitrogen Temporal Trends

In spite of the net loss in nitrate+nitrite at various locations along the Elbow River in these sampling years, a significant increasing trend in nitrate+nitrite concentration occurred at almost all upper Elbow River sites during sampling from 1979 to 2002 (Table 8), except for an upstream reference site at Cobble Flats, above which there are fewer human impacts. An increasing trend was also found in Bragg Creek near the mouth. These results suggest either atmospheric deposition of nitrate+nitrite, or an anthropogenic surface source. A significant increase in this variable also occurred in the Little Elbow River near the mouth (Figure 22, Table 8). The south-west corner of a grazing allotment is upstream from this site, and commercial trail riding also occurs upstream. Although there were only five years of nitrate+nitrite data at this site, the upward trend in concentration remains clear.

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Upper Glenmore Reservoir	1982-2002 (13)	NS
Glenmore Raw Intake	1989-2002 (0.0)	
Elbow River at 9^{th} Ave.	1974-2002 (13)	NS
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Springbank Creek	1989-2002 (3)	
Lott Creek	1988-2002 (6)	NS[a]

[a] Kendall tau test (non-seasonal); NS = no statistically significant trend detected; hyphen indicates insufficient historical data for trend analysis (N < 4 yrs).

Ammonia Nitrogen

Total ammonia is the most reduced form of inorganic nitrogen in water, and includes both dissolved ammonia (NH_3) and the ammonium ion (NH_4^+).

Elbow River Sites

Ammonia concentrations in the Elbow River were typically low among all years and all sites, from 0.005 mg/L to 0.010 mg/L, and below detection limits for the majority of the season except at Twin Bridges and Weaselhead Bridge.

In 1999, 2000, and 2002 there were significant differences among sites in ammonia concentrations ($P<0.05$). In 1999, post-hoc statistical testing failed to discern sites among which concentrations differed. At sites upstream from Weaselhead Bridge medians were all 0.005 mg/L in 1999, and only 0.008 mg/L at the Weaselhead Bridge (Figure 23). In 2000, ammonia concentrations were significantly lower at the Glencoe GCC (0.005 mg/L) than the Hwy 22 Bridge, Twin Bridges and the Weaselhead Bridge (all 0.010 mg/L) ($P<0.05$). In 2002, median concentrations both above Bragg Creek and Glencoe GCC (0.005 mg/L) were significantly lower than at Twin Bridges, Discovery Ridge and Sarcee Bridge, all at 0.010 mg/L ($P<0.05$).

Peak ammonia concentrations tended to occur early in the sampling season, with maximum values observed primarily in April or May. Peak concentrations ranging from 0.02 to 0.05 mg/L in 1999 occurred among all sites (Figure 23), with detectable levels from April to early June, well in advance of the peak river flow for that year. In 2000, peak values from 0.06 to 0.10 mg/L at the Weaselhead Bridge occurred primarily in early May. In 2002, peak concentrations were lower than in previous years, from 0.02 to 0.06 mg/L, occurring in late May (Hwy 22 Bridge and Weaselhead Bridge), mid-June (Twin Bridges), and mid-July (above Bragg Creek and Glencoe GCC).

Elbow River Tributary Sites

Statistically significant differences in ammonia concentrations were observed among tributaries for all years ($P<0.05$). In 1999, 2000, and 2001, ammonia concentrations were significantly higher in Lott Creek than all other tributaries ($P<0.05$), with medians varying from 0.09 mg/L in 2001 to 0.16 mg/L in 1999 (Figure 24). In 2002, ammonia in Lott Creek was slightly lower in concentration than in previous years with a median of 0.03 mg/L, but still significantly greater than Bragg and Pirmez Creeks ($P<0.05$) at 0.005 to 0.010 mg/L. Ammonia concentrations were consistently below detection limit for all the tributaries in the upper reaches of the Elbow River, including the Little Elbow River, Prairie Creek, and McLean Creek, for all years of the study.

Peak ammonia concentrations in Lott Creek samples ranged from 0.13 mg/L in 2002, to 0.15 mg/L in 2001, 0.25 mg/L in 2000 and 0.38 mg/L in 1999 (Figure 24). The greatest values were recorded in samples from 1999 at Millburn and Springbank Creeks at 0.55 mg/L and 0.52 mg/L, respectively. Seasonally, peak ammonia concentrations in tributaries occurred early in the sampling season, primarily in April 1999 and 2002, and May 2000, and were not associated with the mountain snowmelt runoff period of June or July.

Possible sources of ammonia on tributary streams include runoff from agriculture, natural release from decomposition in beaver ponds and other impoundments and aquaculture on Lott Creek. Ammonia in samples from all sites was consistently below the Canadian Water Quality Guidelines for aquatic life, and accordingly did not impair water quality.

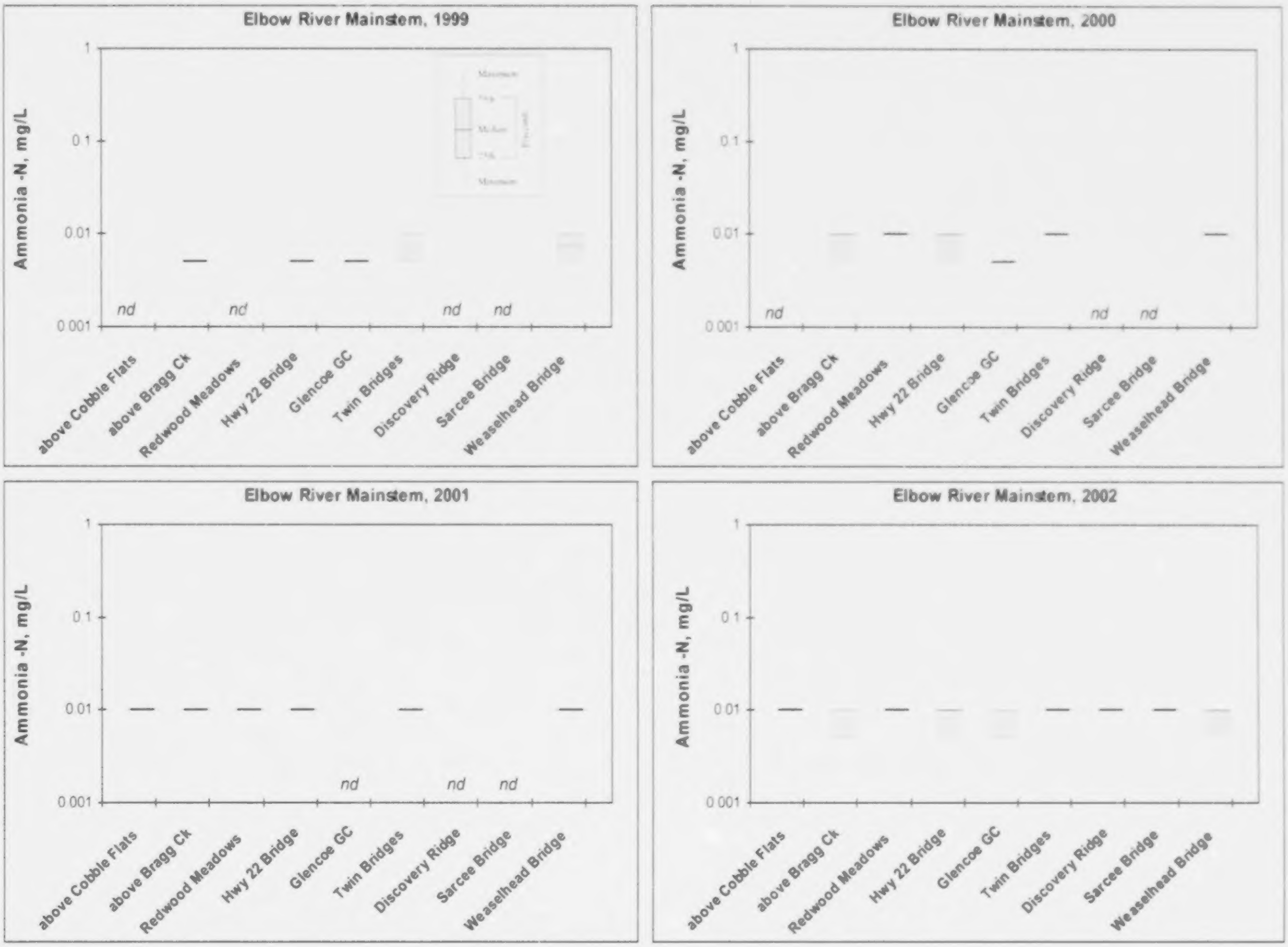

Figure 23. Ammonia nitrogen at Elbow River mainstem sites: March to September, 1999-2002 *(nd=no data)*.

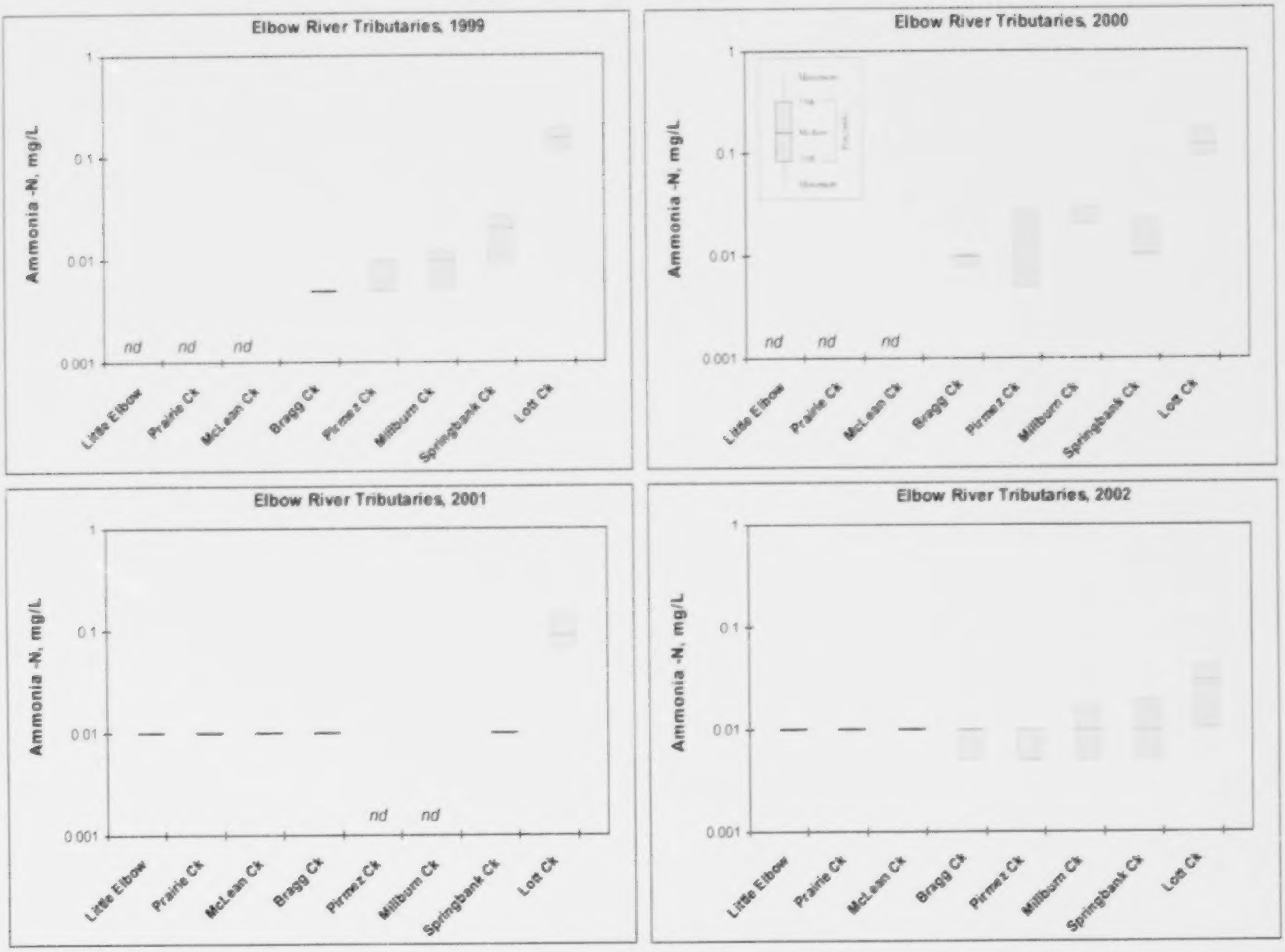

Figure 24. Ammonia nitrogen at Elbow River tributary sites: March to September, 1999-2002 *(nd=no data).*

Ammonia Nitrogen Mass Flux

It was not possible to estimate ammonia mass flux at all sites in 1999 and 2000, but in 2002 the net mass of total ammonia increased between sites along the Elbow River from the Hamlet of Bragg Creek to Twin Bridges, then declined between Sarcee Bridge and Weaselhead Bridge (Figure 25, Table 9). This pattern of mass flux was the opposite of the pattern generally observed with nitrate+nitrite (Figure 21). The pattern of ammonia mass flux could perhaps reflect loading during high runoff upstream from Twin Bridges, and biological uptake near the Weaselhead. However, since ammonia concentrations were generally quite low, this loading pattern could be strongly influenced by differences in flow between sites, rather than true changes in mass.

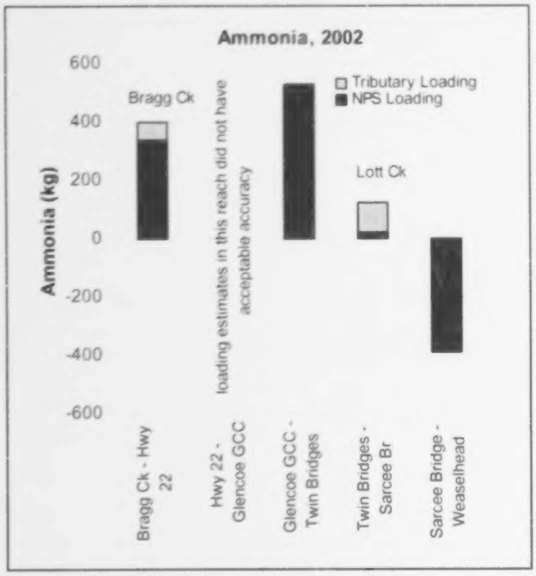

Figure 25. Mass flux of ammonia nitrogen (kg per sampling season) from tributaries and non-point sources for Elbow River reaches: April 15 to August 1, 2002.

Table 9. Mass flux for ammonia nitrogen (kg per sampling season, coefficients of variation in parentheses) for the Elbow River and its major tributaries between Bragg Creek and Weaselhead Bridge. Less reliable estimates (CV >0.2) are in bold italics.

	Ammonia Nitrogen, kg		
Sites	**1999**	**2000**	**2002**
Elbow River			
Above Bragg Creek	382 (0.060)	***429 (0.220)***	1,453 (0.173)
Redwood Meadows			-
Highway 22 Bridge	433 (0.122)	***635 (0.351)***	1,854 (0.131)
Glencoe GCC	***481 (0.276)***	***1,016 (0.226)***	1,505 (0.147)
Twin Bridges	462 (0.190)	***815 (0.264)***	2,033 (0.126)
Sarcee Bridge			2,158 (0.000)
Weaselhead Bridge	***677 (0.291)***	***1,430 (0.266)***	1,765 (0.088)
Elbow River Tributaries			
Bragg Creek	13 (0.00)	***64 (0.239)***	61 (0.126)
Pirmez Creek	***32 (0.230)***	***29 (0.243)***	31 (0.082)
Millburn Creek	14 (0.195)	10 (0.189)	***7 (0.501)***
Springbank Creek	***7 (0.463)***	4 (0.173)	1 (0.195)
Lott Creek	294 (0.097)	223 (0.116)	103 (0.154)

Redwood Meadows and Sarcee Bridge not sampled in 1999 and 2000; hyphen indicates insufficient data to prepare mass flux estimate.

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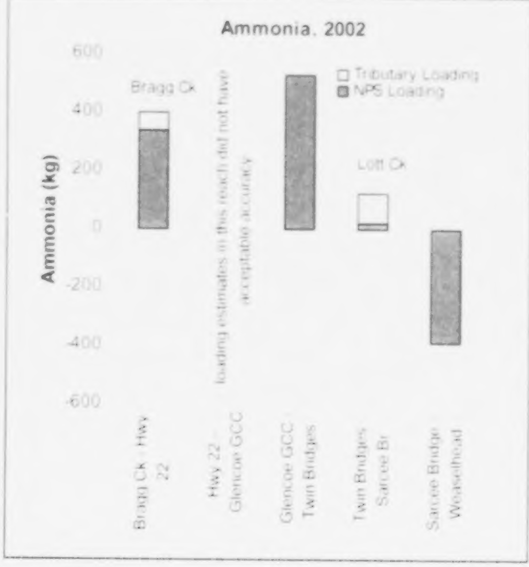

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Ammonia Nitrogen Temporal Trends

Along with TDP, ammonia levels have also increased significantly over time at Twin *Bridges (Table 10). Although this trend was* statistically significant, there were only six complete years of total ammonia measurements at this site and more sampling is needed to verify this trend. Small declining trends in total ammonia were found in the Elbow River above Bragg Creek, and in McLean Creek (Table 10). Reasons for these small changes in ammonia concentration are not known.

Table 10. Significant monotonic trends for ammonia nitrogen in the Elbow River and its major tributaries.

	Sen Slope (units/yr) for significant trends (seasonal kendall tau test, except as indicated[a])	
Sites	Time Period/ (yrs of data)	Ammonia Nitrogen, µg/L
Elbow River Mainstem		
Cobble Flats	1988-2002 (3)	
Above Bragg Creek	1979-2002 (5)	**-<0.01[a]**
Highway 22 Bridge	1979-2002 (7)	NS
Glencoe GCC	1979-2002 (8)	NS[a]
Twin Bridges	1979-2002 (6)	**+<0.01**
Weaselhead Bridge	1988-2002 (10)	NS[a]
Upper Glenmore Reservoir	1982-2002 (13)	NS[a]
Glenmore Raw Intake	1989-2002 (0)	
Elbow River at 9th Ave	1974-2002 (13)	**-<0.01[a]**
Elbow River Tributaries		
Little Elbow River	1978-2002 (5)	NS[a]
McLean Creek	1978-2002 (6)	**-<0.01[a]**
Bragg Creek	1988-2002 (6)	NS[a]
Pirmez Creek	1989-2002 (3)	
Millburn Creek	1999-2002 (3)	
Springbank Creek	1989-2002 (3)	
Lott Creek	1988-2002 (6)	NS[a]

[a] Kendall tau test (non-seasonal); NS = no statistically significant trend detected; hyphen indicates insufficient historical data for trend analysis (N < 4 yrs)

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Glenmore Raw Intake	1989-2002 (0)	-
Elbow River at 9th Ave.	1974-2002 (13)	**-<0.01[a]**
Elbow River Tributaries		
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McLean Creek	1978-2002 (6)	**-<0.01[a]**
Bragg Creek	1988-2002 (6)	NS[a]
Pirmez Creek	1989-2002 (3)	-
Millburn Creek	1999-2002 (3)	-
Springbank Creek	1989-2002 (3)	-
Lott Creek	1988-2002 (6)	NS[a]

[a] Kendall tau test (non-seasonal); NS = no statistically significant trend detected; hyphen indicates insufficient historical data for trend analysis (N < 4 yrs).

Total Kjeldahl Nitrogen

TKN is a measure of organic nitrogen and ammonia, which may result from inputs of nitrogenous organic matter from natural watershed sources, instream biological activities, or anthropogenic inputs from agriculture, or sewage/septic discharges (McNeely et al., 1979).

Elbow River Sites

In all years there were no significant differences in TKN among mainstem sites (*P*>0.05), and concentrations exhibited no obvious longitudinal pattern (Figure 26). Median concentrations in the Elbow River ranged from 0.08 to 0.17 mg/L in 1999, 2000 and 2001, and were moderately higher in 2002, varying from 0.12 mg/L above Bragg Creek site to 0.26 mg/L at Sarcee Bridge.

Seasonally, TKN concentrations tended to peak early in the season, and declined from summer to fall. Maximum concentrations were not necessarily associated with runoff discharges. In 1999, peak TKN concentrations, ranged from 0.86 mg/L at Twin Bridges to 1.7 mg/L at the Glencoe GCC site (Figure 26), all during mid-April. In contrast, high TKN concentrations from 2000 to 2002 were often associated with the mountain snowmelt runoff period in June. In 2002, peak concentrations at Hwy 22 Bridge (0.44 mg/L), Glencoe GCC (0.63 mg/L), Twin Bridges (0.71 mg/L), and the Weaselhead Bridge (0.83 mg/L), all occurred in mid-June at the height of the spring runoff.

Elbow River Tributary Sites

In all years sampled, there were significant differences in TKN concentrations among tributaries (*P*<0.05). Millburn Creek generally had the greatest TKN concentrations, with medians varying from 0.58 mg/L in 2000 to 0.66 mg/L in 2002 (Figure 27). Millburn Creek TKN was significantly greater than Pirmez Creek in 1999, greater than Lott Creek in 2000, and significantly greater than Bragg Creek, Pirmez Creek, Springbank Creek and Lott Creek in 2002 (*P*<0.05). Pirmez Creek, in contrast, had lower median TKN concentrations, ranging from 0.11 mg/L to 0.19 mg/L in 1999 and 2002. Bragg Creek, Springbank Creek and Lott Creek occupied an intermediate range of concentrations. Tributaries above Bragg Creek were not sampled for TKN in any year, which precluded comparisons among upper and lower tributary sites.

Seasonally, peak TKN concentrations attained maximum levels early in the sampling season, usually before the June/July runoff periods, and concentrations declined through the summer to the fall. In 1999, maximum concentrations occurred in April, ranging from 0.9 mg/L at Lott Creek to 4.0 mg/L at Millburn Creek (Figure 27). In 2000, peak concentrations generally occurred in May, although overall the maximum for that year was observed at Millburn Creek with a 1.37 mg/L value reported in mid-July. In 2002, peak TKN ranged from 0.34 mg/L at Lott Creek to 1.34 mg/L at Millburn Creek, all occurring in April to mid-May.

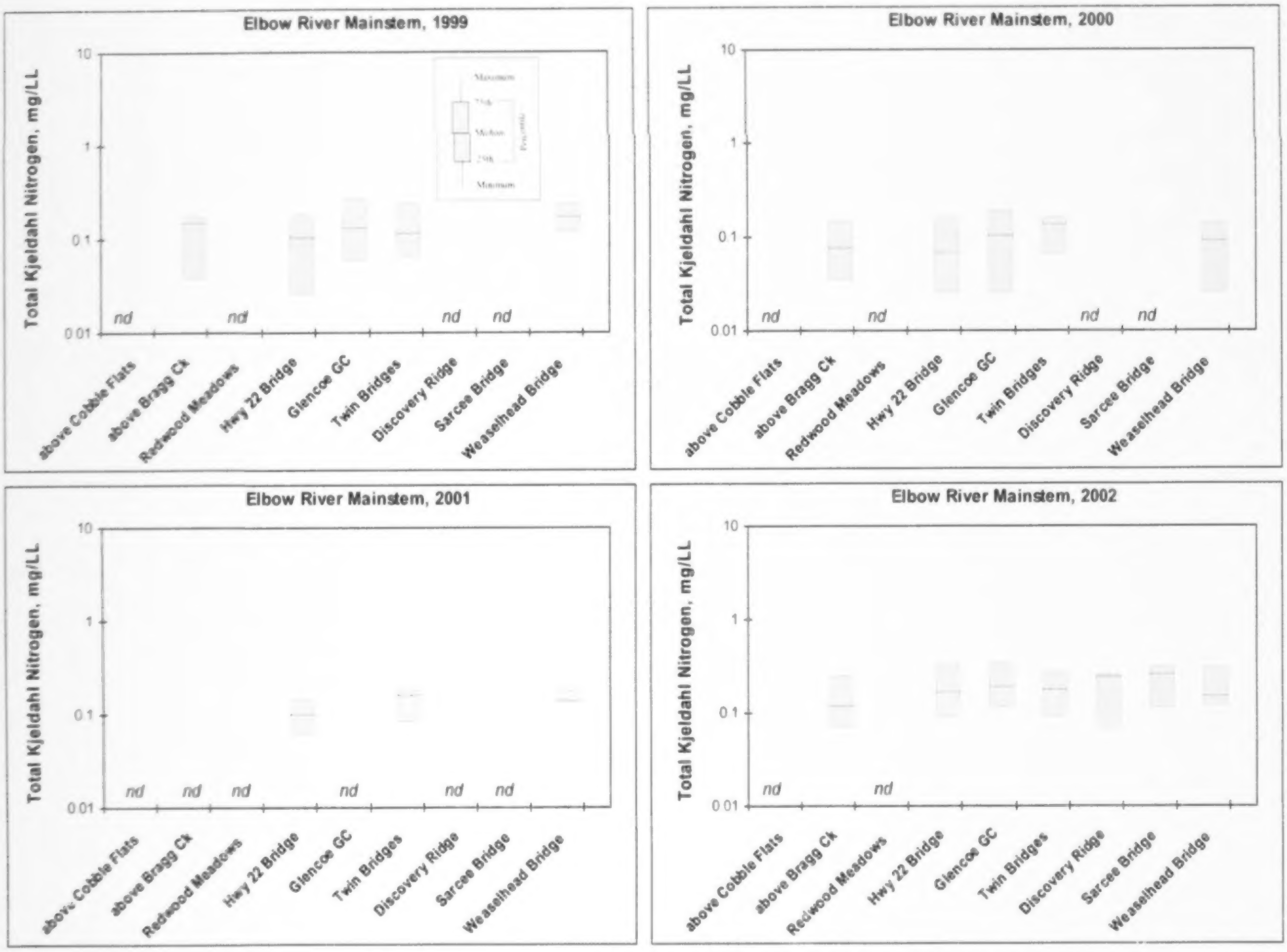

Figure 26. Total kjeldahl nitrogen at Elbow River mainstem sites: March to September, 1999-2002 *(nd=no data)*.

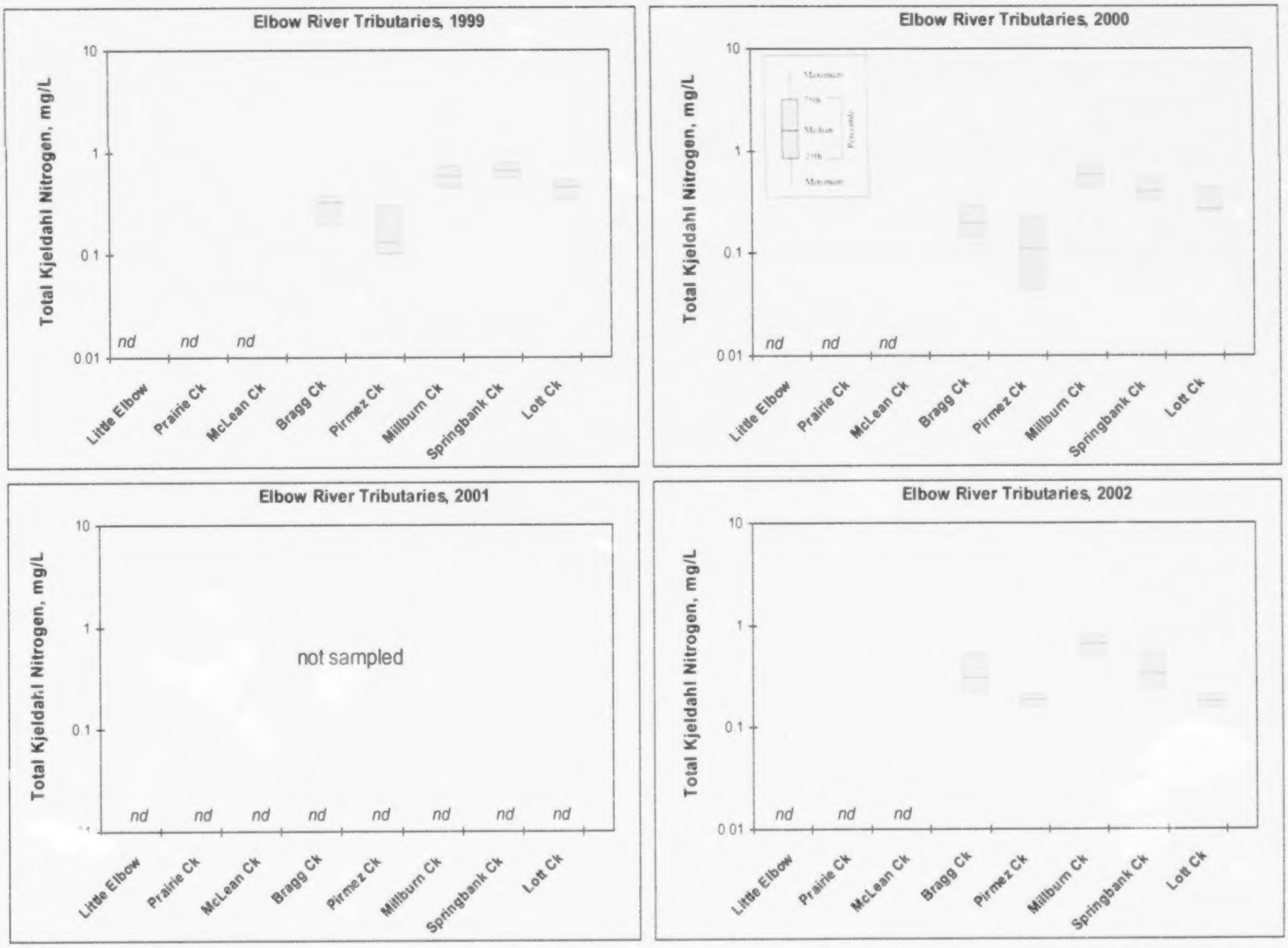

Figure 27. Total kjeldahl nitrogen at Elbow River tributary sites: March to September, 1999, 2000, and 2002 *(nd=no data).*

Total Nitrogen

Total nitrogen (TN) is a combined measure of all forms of organic (calculated as TKN minus ammonia) and inorganic nitrogen (nitrate, nitrite, and ammonia), and can be determined when the components are individually measured.

Elbow River Sites

There was no apparent longitudinal pattern of TN concentration (Figure 28), and no significant differences in concentration among sites for any year sampled (P>0.05). In the Elbow River above Bragg Creek median TN concentrations varied from 0.20 mg/L in 2000 to 0.24 mg/L in 1999. Twin Bridges median TN ranged from 0.19 mg/L in 1999 and 2000 to 0.28 mg/L in 2002, and at the Weaselhead Bridge site ranged from 0.16 mg/L in 2000 to 0.28 mg/L in 1999.

Seasonally, TN concentrations followed a pattern similar to TKN concentrations, increasing early in the sampling season, and then decreasing through summer and fall, with maximum concentrations occurring either before or during the period of runoff from mountain snowmelt. The highest concentrations were found in 1999, with maximums ranging from 0.96 mg/L at Twin Bridges to 1.83 mg/L at Glencoe GCC (Figure 28), all during the early runoff in mid-April. In 2000, 2001, and 2002, peak concentrations were less than 1 mg/L, except for one instance at the Weaselhead Bridge in 2000 (1.03 mg/L). In those years, TN concentrations peaked from mid-May to mid-June.

Among mainstem sites there was a very low exceedance rate of the 1 mg/L TN guideline (Alberta Surface Water Quality Guidelines). This guideline was only exceeded in 2% of samples from sites at the Elbow River above Bragg Creek, Hwy 22 Bridge, Glencoe GCC and Twin Bridges (only 1 sample at each site exceeded the guideline), in 1999, and 3% of samples from Weaselhead Bridge (2 occurrences in 64 samples) in 1999 and 2000.

Elbow River Tributary Sites

In 1999, there was no significant difference in TN concentration among tributary sites (P>0.05), with medians varying from 0.39 mg/L at Bragg and Pirmez Creeks to 0.68 mg/L at Springbank Creek (Figure 29). Significant differences among tributaries were found in both 2000 and 2002 (P<0.05), as TN concentrations at both Springbank and Millburn Creeks (medians from 0.53 to 0.58 mg/L) were significantly greater than Bragg and Pirmez Creeks (medians from 0.25 to 0.29 mg/L) in 2000. TN concentrations in Pirmez and Millburn Creeks (medians from 0.67 to 0.71 mg/L) were significantly greater than TN in Bragg Creek (0.40 mg/L) and Lott Creek (0.28 mg/L) in 2002 (P<0.05).

Seasonally, TN concentrations in tributaries followed a pattern similar to TKN, with high concentrations in the early season, decreasing through summer to fall. Maximum TN concentrations in 1999 ranged from 1.05 mg/L at Lott Creek to 4.21 mg/L at Millburn (Figure 29), all during the early snowmelt runoff in mid-April. Maximum TN concentrations were lower in 2000, ranging from 0.73 mg/L to a high of 1.40 mg/L at Millburn Creek. TN concentrations were also lower in 2002 with peaks from 0.44 mg/L at Lott Creek to 1.54 mg/L at Millburn Creek, generally during the higher flows of mid-May to mid-June.

The 1 mg/L Alberta Surface Water Quality Guideline was seldom exceeded in the tributaries. Only 2% of samples from Springbank and Lott Creeks, 5% from Bragg Creek, and 7% from Pirmez and Millburn Creeks exceeded this guideline for an overall rate of 5%. Most exceedances occurred in 1999, with two other occasions at Millburn Creek in 2000 and 2002, and two at Pirmez Creek in 2002.

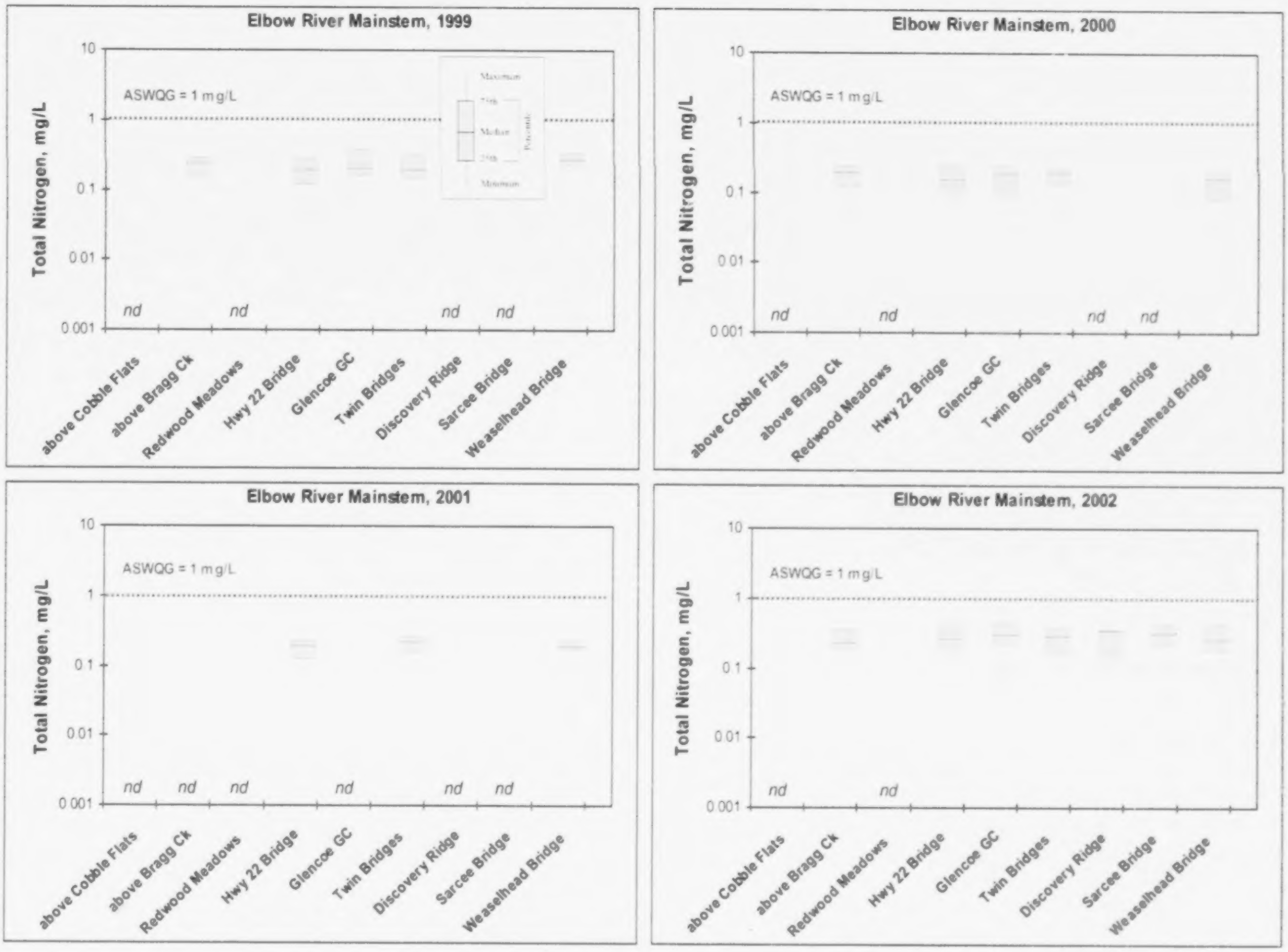

Figure 28. Total nitrogen at Elbow River mainstem sites: March to September, 1999-2002 (*nd=no data*).

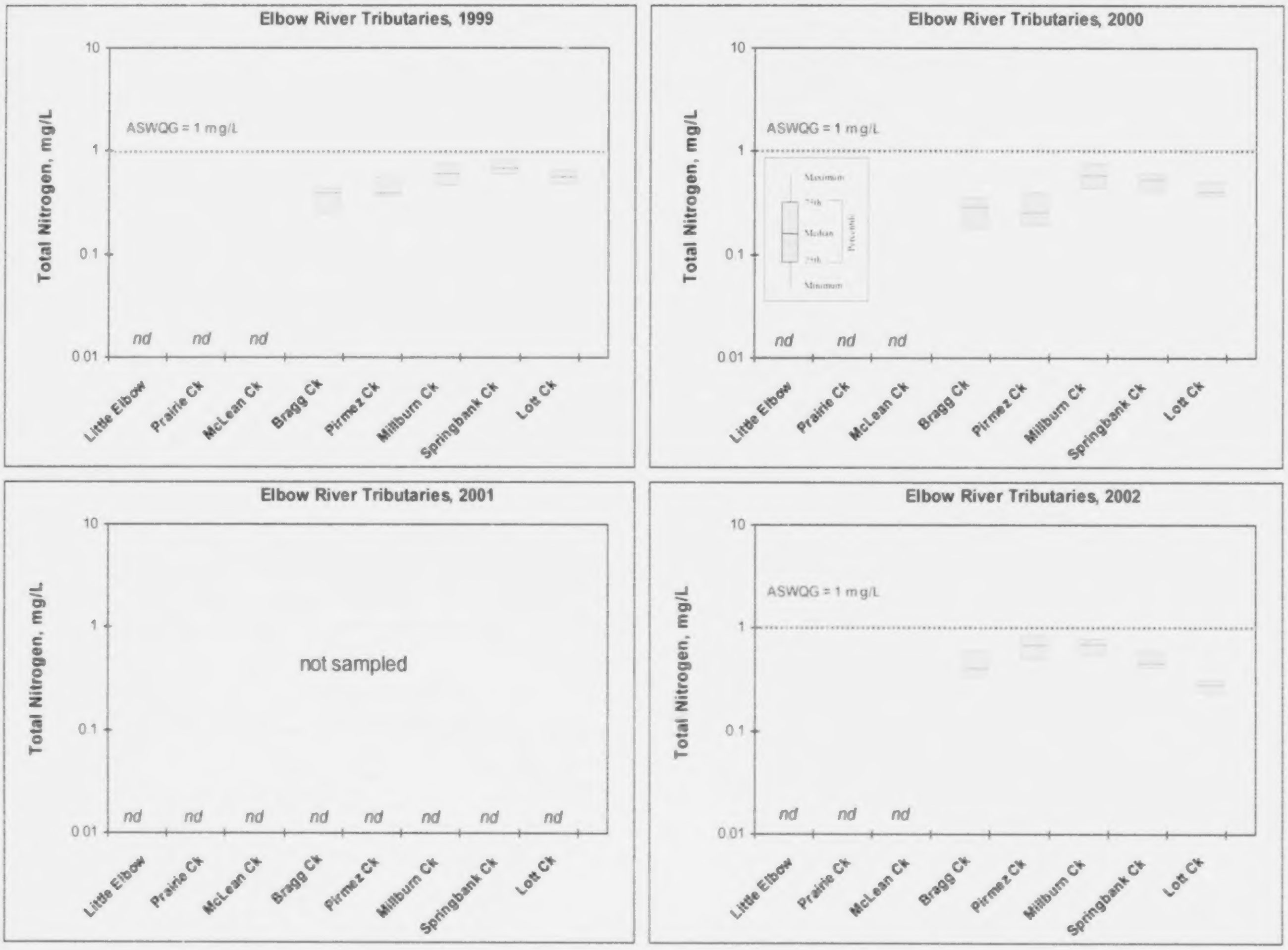

Figure 29. Total nitrogen at Elbow River tributary sites: March to September, 1999, 2000, and 2002 (*nd=no data*).

Total Kjeldahl Nitrogen and Total Nitrogen Mass Flux

TN and TKN net mass flux generally followed the same pattern as nitrate+nitrite in 1999 and 2000 with a loss of mass along some reaches of the Elbow River, and evidence of loading close to Calgary from nonpoint sources and Lott Creek in 1999 and 2002 (Figure 30, Table 11). Nonpoint source loading, rather than a loss of these forms of nitrogen, occurred in 2002 along each reach of the Elbow River between the Hamlet of Bragg Creek and the Glencoe GCC. The reasons for higher nonpoint source contribution of TN and TKN in 2002 are not known. Possibilities include more diffuse runoff during a wetter year and more scouring of material from the flood plain. As often occurs in surface water, TKN mass was a large proportion of the TN mass at most sites, usually ≥ 61% (Table 11). Since ammonia concentrations were consistently low (Figure 23), TKN was predominantly organic nitrogen. The only site where TKN mass was consistently a lower proportion of TN mass was at Pirmez Creek near the mouth (range: 28-41%) where the mass of nitrate+nitrite was greater than that of TKN. This lower proportion could reflect a large groundwater contribution of nitrate+nitrite from springs in the headwaters of Pirmez Creek.

Tributaries contributed a greater mass of TKN and TN to the Elbow River than nonpoint sources in 1999 and 2000 (Figure 30). Although TKN and TN median concentrations were generally highest in Millburn Creek (Figures 27 and 29), Lott Creek

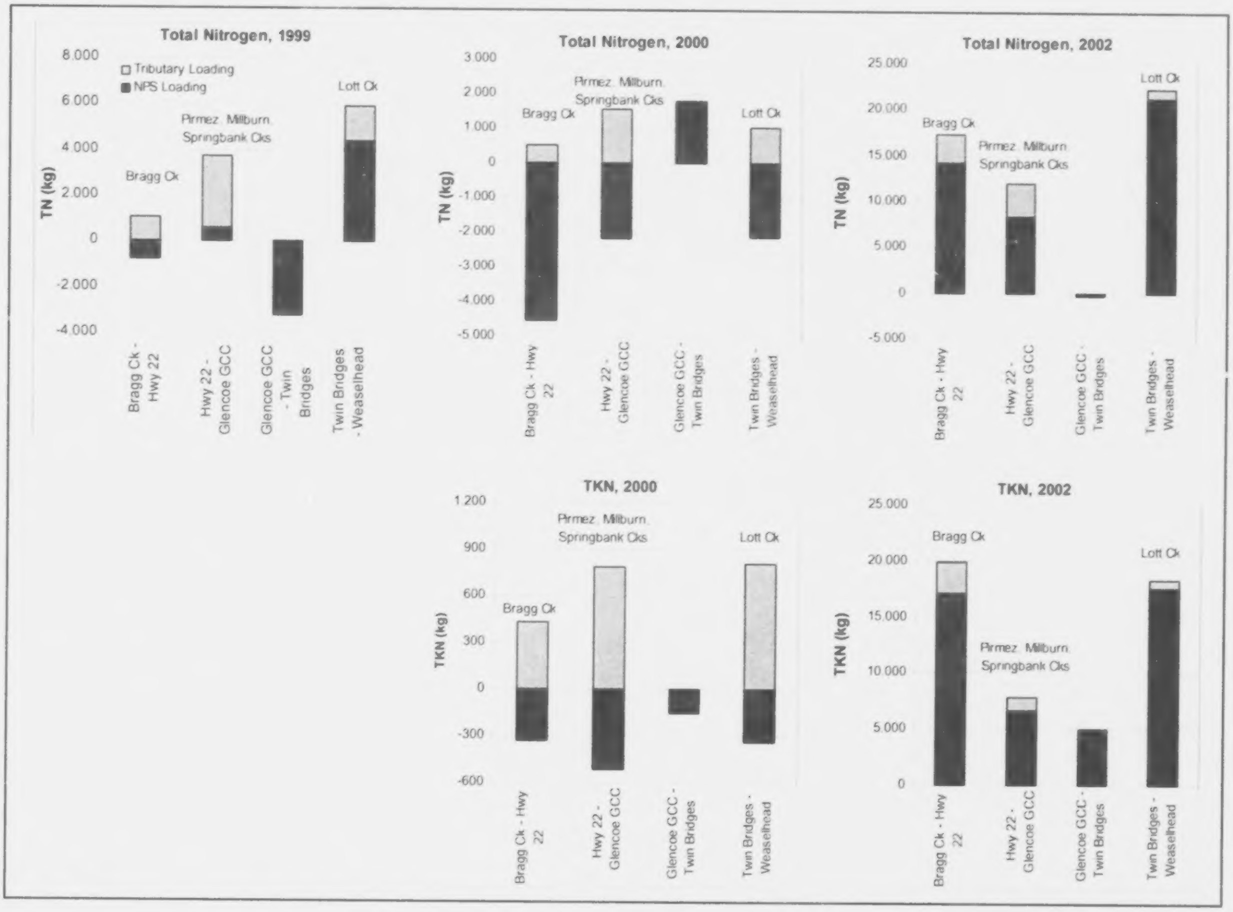

Figure 30. Mass flux of total nitrogen and total kjeldahl nitrogen (kg per sampling season) from tributaries and non-point sources for Elbow River reaches: April 7 to July 8, 1999; May 1 to August 1, 2000; April 15 to August 1, 2002.

Table 11. Mass flux for total kjeldahl nitrogen and total nitrogen (kg per sampling season, coefficients of variation in parentheses) for the Elbow River and its major tributaries between Bragg Creek and Weaselhead Bridge. Less reliable estimates (CV >0.2) are in bold italics.

	Total Kjeldahl Nitrogen, kg			Total Nitrogen, kg		
Sites	**1999**	**2000**	**2002**	**1999**	**2000**	**2002**
Elbow River						
Above Bragg Creek	***11,285 (0.204)***	7,807 (0.150)	48,063 (0.135)	18,596 (0.163)	15,972 (0.110)	69,483 (0.088)
Redwood Meadows						
Highway 22 Bridge	***12,371 (0.266)***	7,904 (0.197)	67,891 (0.071)	18,890 (0.181)	11,923 (0.133)	86,830 (0.043)
Glencoe GCC	***13,561 (0.204)***	8,172 (0.047)	75,696 (0.114)	22,602 (0.180)	11,270 (0.165)	98,826 (0.100)
Twin Bridges	***12,561 (0.231)***	8,016 (0.190)	80,617 (0.131)	19,385 (0.156)	13,053 (0.124)	98,530 (0.092)
Sarcee Bridge						
Weaselhead Bridge	17,331 (0.182)	8,487 (0.126)	98,838 (0.106)	25,285 (0.133)	11,951 (0.085)	120,835 (0.081)
Elbow River Tributaries						
Bragg Creek	968 (0.062)	429 (0.175)	2,729 (0.044)	1,075 (0.064)	515 (0.151)	3,179 (0.035)
Pirmez Creek	***967 (0.245)***	504 (0.185)	966 (0.041)	2,694 (0.084)	1,243 (0.070)	3,425 (0.066)
Millburn Creek	307 (0.188)	237 (0.075)	233 (0.080)	311 (0.187)	239 (0.076)	241 (0.089)
Springbank Creek	110 (0.078)	44 (0.063)	30 (0.066)	113 (0.091)	54 (0.069)	34 (0.050)
Lott Creek	1,192 (0.064)	806 (0.116)	710 (0.065)	1,489 (0.052)	1,038 (0.088)	1,054 (0.048)

Redwood Meadows and Sarcee Bridge not sampled in 1999 and 2000; hyphen indicates insufficient data to prepare mass flux estimate.

contributed the greatest mass of TKN in 1999 and 2000, and Bragg Creek was the greatest tributary source of TKN in 2002. Presumably, the greater contribution of TKN in Bragg Creek in 2002 was related to higher runoff that year, as peak flows were much higher during sampling in Bragg Creek that year than in 1999 and 2000. Pirmez Creek contributed the greatest TN mass of any tributary in all years sampled (Table 11). In most years this TN mass in Pirmez Creek was largely comprised of nitrate+nitrite (Table 7).

Total Kjeldahl Nitrogen and Total Nitrogen Temporal Trends

Total kjeldahl nitrogen and total nitrogen displayed no significant trends in the upper Elbow basin, with significantly decreasing trends only evident in the upper Glenmore Reservoir and the lower Elbow River near the mouth (Table 12).

Among tributaries, only Bragg Creek showed a significant decreasing trend in total kjeldahl nitrogen, with no significant trend in either TN or TKN at Lott Creek (Table 12). There were insufficient data to assess trend among other Elbow tributaries.

Table 12. Significant monotonic trends for total kjeldahl nitrogen and total nitrogen in the Elbow River and its major tributaries.

		Sen Slope (units/yr) for significant trends (seasonal kendall tau test, except as indicated[a])	
Sites	Time Period/ (yrs of data)	Total Kjeldahl Nitrogen µg/L	Total Nitrogen µg/L
Elbow River Mainstem			
Cobble Flats	1988-2002 (1, 1)	–	–
Above Bragg Creek	1979-2002 (4, 4)	NS	NS
Highway 22 Bridge	1979-2002 (7, 7)	NS	NS
Glencoe GCC	1979-2002 (8, 8)	NS[a]	NS[a]
Twin Bridges	1979-2002 (8, 10)	NS	NS
Weaselhead Bridge	1988-2002 (12, 6)	NS[a]	NS[a]
Upper Glenmore Reservoir	1982-2002 (9, 9)	**-5.1**	**-6.3**
Glenmore Raw Intake	1989-2002 (0, 0)	–	–
Elbow River at 9th Ave.	1976-2002 (12, 12)	**-6.9**	**-12.6**
Elbow River Tributaries			
Little Elbow River	1978-2002 (3, 3)	–	–
McLean Creek	1978-2002 (3, 4)	–	–
Bragg Creek	1988-2002 (5, 5)	**-6.7**	NS[a]
Pirmez Creek	1990-2002 (3, 3)	–	–
Millburn Creek	1990-2002 (3, 3)	–	–
Springbank Creek	1989-2002 (3, 3)	–	–
Lott Creek	1988-2002 (5, 5)	NS[a]	NS[a]

[a] Kendall tau test (non-seasonal); NS = no statistically significant trend detected; hyphen indicates insufficient historical data for trend analysis (N < 4 yrs).

Table 11. Mass flux for total kjeldahl nitrogen and total nitrogen (kg per sampling season, coefficients of variation in parentheses) for the Elbow River and its major tributaries between Bragg Creek and Weaselhead Bridge. Less reliable estimates (CV >0.2) are in bold italics.

	Total Kjeldahl Nitrogen, kg			Total Nitrogen, kg		
Sites	**1999**	**2000**	**2002**	**1999**	**2000**	**2002**
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Above Bragg Creek	***11,285 (0.204)***	7,807 (0.150)	48,063 (0.135)	18,596 (0.163)	15,972 (0.110)	69,483 (0.088)
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Redwood Meadows and Sarcee Bridge not sampled in 1999 and 2000; hyphen indicates insufficient data to prepare mass flux estimate

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Total Kjeldahl Nitrogen and Total Nitrogen Temporal Trends

Total kjeldahl nitrogen and total nitrogen displayed no significant trends in the upper Elbow basin, with significantly decreasing trends only evident in the upper Glenmore Reservoir and the lower Elbow River near the mouth (Table 12).

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Table 12. Significant monotonic trends for total kjeldahl nitrogen and total nitrogen in the Elbow River and its major tributaries.

		Sen Slope (units/yr) for significant trends (seasonal kendall tau test, except as indicated[a])	
Sites	Time Period/ (yrs of data)	Total Kjeldahl Nitrogen µg/L	Total Nitrogen µg/L
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Above Bragg Creek	1979-2002 (4, 4)	NS	NS
Highway 22 Bridge	1979-2002 (7, 7)	NS	NS
Glencoe GCC	1979-2002 (8, 8)	NS[a]	NS[a]
Twin Bridges	1979-2002 (8, 10)	NS	NS
Weaselhead Bridge	1988-2002 (12, 6)	NS[a]	NS[a]
Upper Glenmore Reservoir	1982-2002 (9, 9)	**-5.1**	**-6.3**
Glenmore Raw Intake	1989-2002 (0, 0)		
Elbow River at 9th Ave	1976-2002 (12, 12)	**-6.9**	**-12.6**
Elbow River Tributaries			
Little Elbow River	1978-2002 (3, 3)		
McLean Creek	1978-2002 (3, 4)		
Bragg Creek	1988-2002 (5, 5)	**-6.7**	NS[a]
Pirmez Creek	1990-2002 (3, 3)		
Millburn Creek	1990-2002 (3, 3)		
Springbank Creek	1989-2002 (3, 3)		
Lott Creek	1988-2002 (5, 5)	NS[a]	NS[a]

[a] Kendall tau test (non-seasonal); NS = no statistically significant trend detected; hyphen indicates insufficient historical data for trend analysis (N < 4 yrs)

Total Suspended Solids

Total suspended solids (TSS), typically measured as non-filterable residue, is the amount of suspended material in a water column, operationally defined as the mass retained on a filter per unit volume of water. The suspension is comprised largely of soil particles derived from land surfaces by erosion, but may include chemical and biochemical precipitates, as well as decomposed organic matter. Turbidity measures the degree to which light is scattered and absorbed as it passes through a sample, and consequently is an indirect measure of the amount of TSS and water clarity.

The concentration of suspended sediment in a stream is closely related to environmental and land-use factors (both urban and agricultural), intensity and volume of precipitation, geology and soil types, and physical characteristics of the stream.

High suspended sediment concentrations may adversely affect stream quality by increasing turbidity, thereby inhibiting photosynthetic activity of algae and higher plants (McNeely et al., 1979). Additionally, high concentrations of suspended sediment may interfere with water treatment, and can be aesthetically undesirable. High levels of suspended sediment may also adversely affect aquatic life by scouring, filling or clogging of sediment interstices, thereby limiting benthic production and reducing fish growth and development.

Bacteria and chemicals such as some pesticides, phosphorus and ammonium, can be adsorbed to sediments and transported to receiving waters. Because of selective erosional sorting, where finer and less dense particles are preferentially and more easily transported than are larger, more dense particles, and because smaller particles have a greater adsorption capacity, eroding sediments generally contain higher concentrations of pollutants than the parent soil (EPA, 2003).

Elbow River Sites

TSS displayed a consistent longitudinal pattern at the Elbow River sites, increasing in concentration from upstream to downstream sites for all years, as medians varied from 0.5 to 10 mg/L in 1999 through 2001, and from 0.2 to 41 mg/L in 2002 (Figure 31).

There were significant differences in TSS concentration among mainstem sites in all years ($P<0.05$). In 1999, 2000, and 2001, concentrations were significantly greater at the Weaselhead site than all other sites sampled, except for Redwood Meadows in 2001 ($P<0.05$), with medians at Weaselhead Bridge varying from 4 to 10 mg/L (Figure 31). In 2002, TSS concentrations at the Weaselhead Bridge (median 34 mg/L) and Glencoe GCC site (median 41 mg/L) were significantly greater than at Cobble Flats, above Bragg Creek, Hwy 22 Bridge and Twin Bridges ($P<0.05$), where medians varied from 0.2 to 8 mg/L.

In the Elbow River, there were two reaches which exhibited marked increases between adjacent sites in most years: the Hwy 22 Bridge to Glencoe GCC reach where median TSS concentrations increased significantly in 2000 and 2002 ($P<0.05$); and Twin Bridges to the Weaselhead Bridge reach with significant increases in TSS between sites in all years ($P<0.05$). These increases were especially evident in 2002, as median concentration increases of 33 mg/L were observed from the Hwy 22 Bridge to the Glencoe GCC site, and 34 mg/L from Twin Bridges to the Weaselhead (Figure 31). TSS deposition was apparent in both 2000 and 2002 in the reach from Glencoe GCC to Twin Bridges, with a significant difference between sites in 2002 ($P<0.05$) as median concentration decreased from 41 to 7 mg/L, a decline of 34 mg/L.

Seasonally, TSS concentrations were low in May, peaked during the spring runoff events of July 1999 and June 2000, 2001, and 2002, and declined thereafter to the September sampling dates. Peak TSS concentrations at all sites were coincident with peak river discharges during the spring runoff event in all years, with maximum concentrations at the Weaselhead Bridge in 1999 and 2000 (1031 mg/L in 1999, 105 mg/L in 2000) (Figure 31). In 2002, the greatest TSS concentration recorded was at the Hwy 22 Bridge (3750 mg/L), although median TSS was higher that year at both the Glencoe GCC and Weaselhead Bridge.

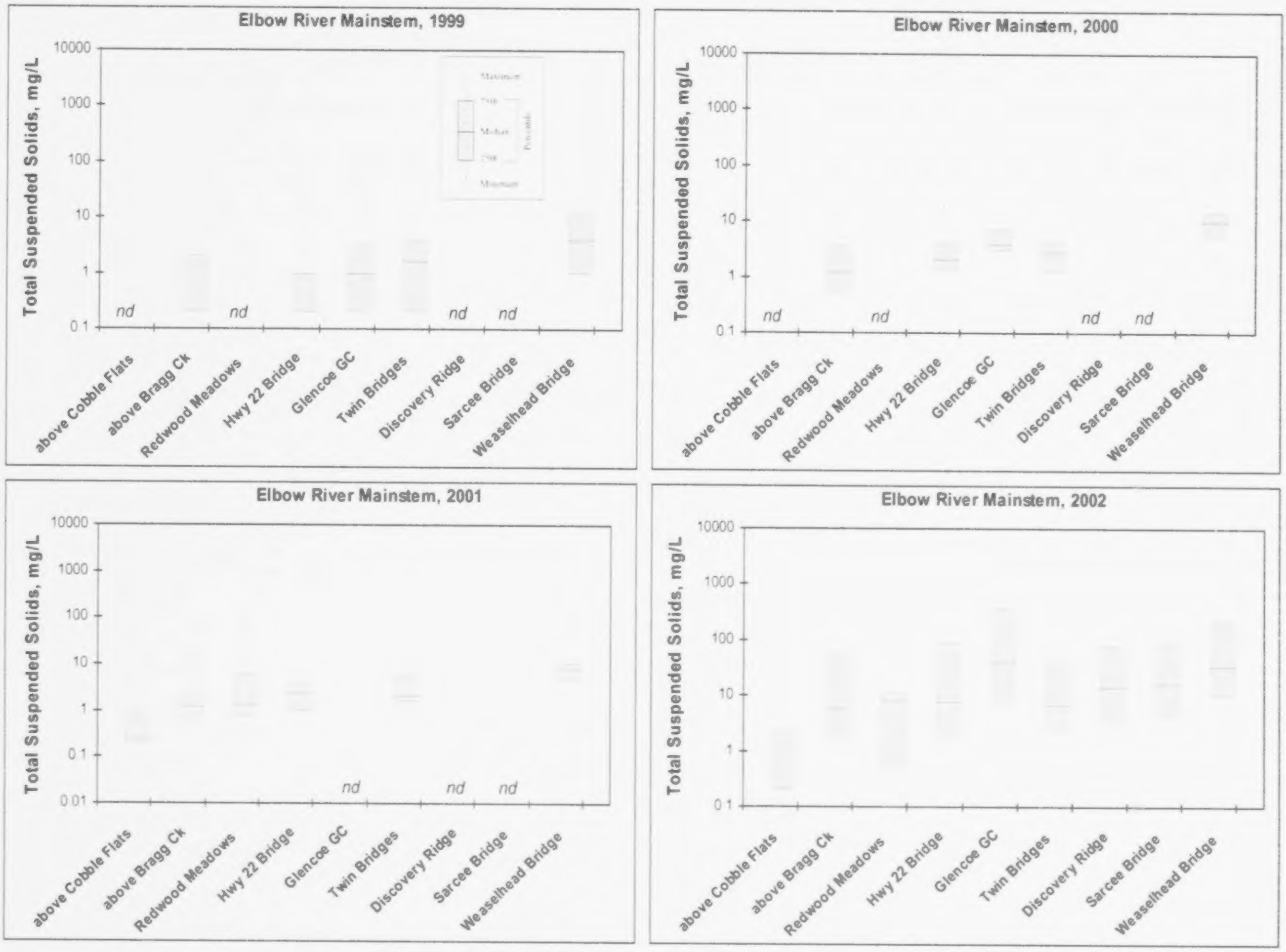

Figure 31. Total suspended solids at Elbow River mainstem sites: March to September, 1999-2002 (*nd=no data*).

Elbow River Tributary Sites

Elbow tributary TSS concentrations were low among all sites and all years, with medians ranging from 0.2 to 5.9 mg/L (Figure 32). There was generally little difference among years, although in 1999 tributary sites in the lower reaches were consistently lower in TSS concentration than in later years, as medians ranged from 0.2 to 0.4 mg/L in 1999 and from 1.2 to 5.2 mg/L in 2000, 2001, and 2002.

TSS concentrations did not differ significantly among tributary sites for 1999, 2000, and 2001 ($P>0.05$). In 2002, there was a significant difference among sites with Pirmez Creek TSS concentrations significantly greater than Lott Creek ($P<0.05$).

Tributaries in the upper reaches of the Elbow River followed a general increasing pattern of concentration in both 2001 and 2002 (Figure 32). Median TSS increased from the Little Elbow (0.2 mg/L in 2001 and 0.4 mg/L in 2002) to Bragg Creek (5.9 mg/L in 2001 and 2.9 mg/L in 2002). TSS median concentrations remained relatively consistent among lower tributary sites, varying from 1.2 to 5.2 mg/L.

Unlike the Elbow River sites where peak TSS concentrations were coincident with peak river discharges associated with the June or early July

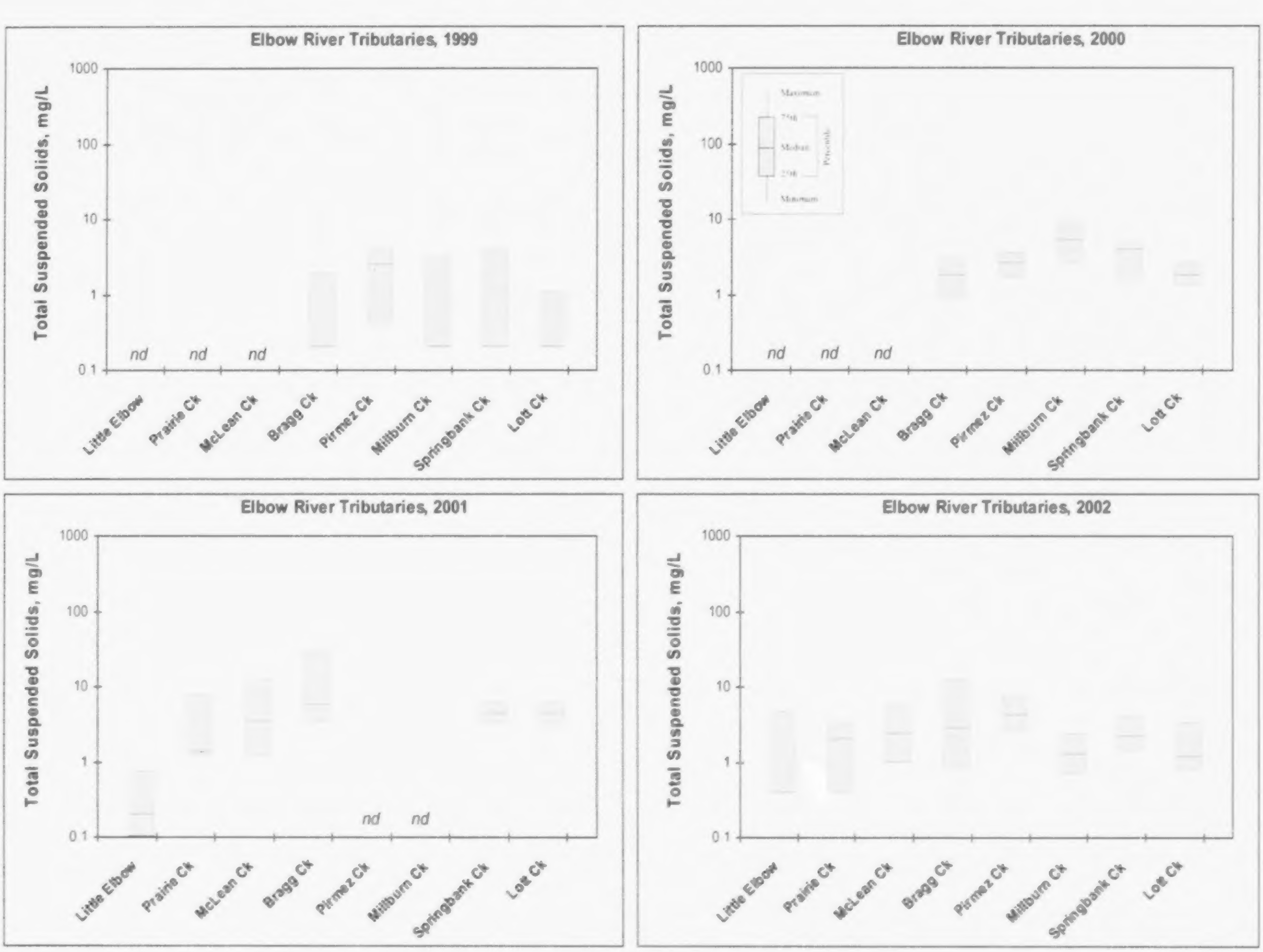

Figure 32. Total suspended solids at Elbow River tributary sites: March to September, 1999-2002 (*nd=no data*).

spring runoff, tributary TSS were much more variable. Peak TSS in the Little Elbow River and Prairie Creek occurred during the June runoff in 2001 and 2002. However, in 2000 and 2002 the remaining sites displayed peak TSS concentrations several weeks preceding the mainstem runoff event. A maximum TSS concentration of 88 mg/L for Bragg Creek in 2002 (Figure 32), for example, occurred on May 14, almost a month prior to the June 19 peak discharge in the Elbow River. This pattern is consistent with the source of runoff discharge for the various tributaries. The Little Elbow River and Prairie Creeks are mountain streams influenced strongly by the mountain snowmelt, whereas the remaining tributaries are largely foothill and parkland streams influenced more by local snowmelt and/or precipitation events that often occur earlier in the season.

Total Suspended Solids Mass Flux

During 2000, when flows were below average, the largest mass influx of TSS occurred between Twin Bridges and the Weaselhead Bridge with an estimated net increase of 725 tonnes attributable to nonpoint sources (Figure 33, Table 13). It was not possible to estimate TSS mass flux for all sites in 1999, but the concentration of TSS was greatest along the Elbow River at Weaselhead Bridge in both 1999 and 2000. A smaller, but still substantial, net influx of TSS mass occurred between the Hamlet of Bragg Creek and the Glencoe GCC in 2000, followed by net deposition of TSS between the Glencoe GCC and Twin Bridges. TP exhibited a similarly large increase in mass between Twin Bridges and Weaselhead in 1999 and 2000. TP includes particulate phosphorus and is highly correlated with TSS (Spearman $\rho = 0.610$, $P<0.05$).

These findings suggest that sources between Twin Bridges and Weaselhead Bridge contribute the bulk of the suspended sediment during low to average flow years. Possible sources include the resuspension of bed material, bank erosion, and nonpoint agricultural runoff. In the lower reach, storm sewers that release urban runoff represent additional influences.

The 2002 mass estimates revealed that a large influx of TSS mass occurred during the high flows of that year between Bragg Creek and Highway 22, more than was contributed by nonpoint sources along any other reach of the Elbow River (Figure 33). Various sites of bank erosion in that reach were identified during the aerial survey in November 2002. Unstable banks were found between the Hamlet of Bragg Creek and Redwood Meadows, opposite a series of wing deflectors on the south bank, and in a side channel on the east bank just upstream from Highway 22 (Maps 1 and 2). Furthermore, a large amount of recently deposited gravel and other sediment was found downstream from Highway 22 (Map 2). Presumably this material was scoured from sites between the Bragg Creek and Highway 22 Bridge.

In 2000, the area of greatest deposition occurred in the reach of the Elbow River from the Glencoe GCC to Twin Bridges (-179 tonnes, Figure 33). During the higher flow of 2002, a substantially

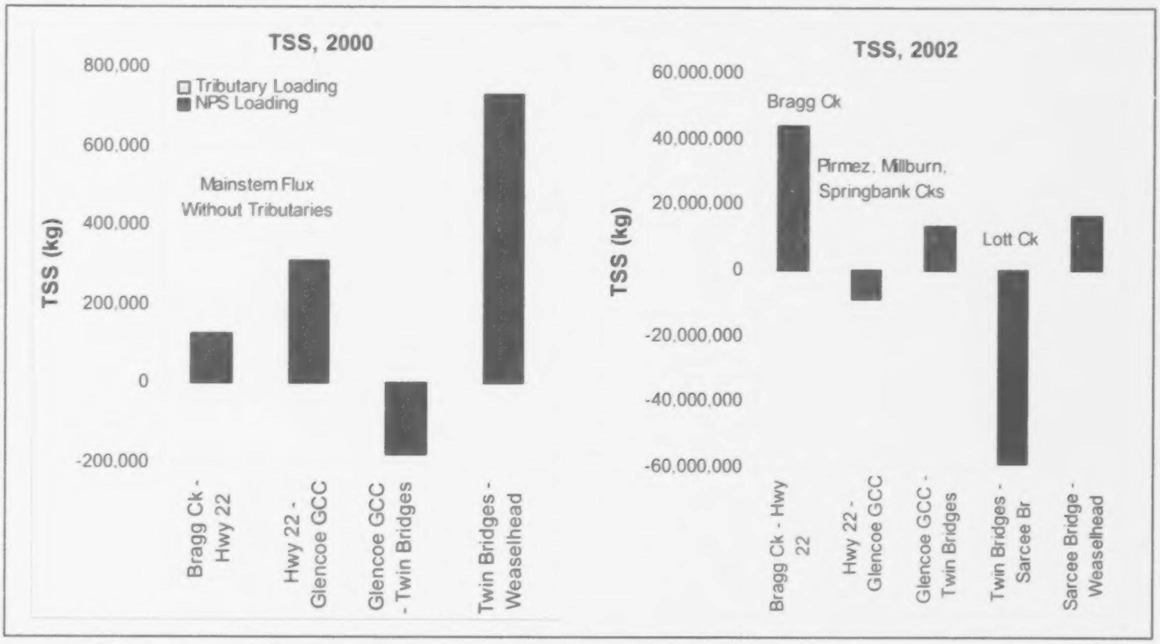

Figure 33. Mass flux of total suspended solids (kg per sampling season) from tributaries and non-point sources for Elbow River reaches: (a) May 1 to August 1, 2000; (b) April 15 to August 1, 2002.

Table 13. Mass flux for total suspended solids (kg per sampling season, coefficients of variation in parentheses) for the Elbow River and its major tributaries between Bragg Creek and Weaselhead Bridge. Less reliable estimates (CV >0.2) are in bold italics.

	Total Suspend Solids, kg		
Sites	**1999**	**2000**	**2002**
Elbow River			
Above Bragg Creek	***952,476 (0.299)***	137,335 (0.122)	57,298,720 (0.181)
Redwood Meadows			-
Highway 22 Bridge	1,244,624 (0.199)	264,173 (0.142)	101,071,100 (0.172)
Glencoe GCC	1,763,821 (0.176)	573,865 (0.162)	92,455,680 (0.129)
Twin Bridges	2,822,856 (0.175)	394,934 (0.083)	105,647,600 (0.130)
Sarcee Bridge			46,907,900 (0.157)
Weaselhead Bridge	***3,618,437 (0.365)***	1,126,208 (0.165)	63,496,990 (0.092)
Elbow River Tributaries			
Bragg Creek	***31,535 (0.401)***	***3,704 (0.244)***	196,353 (0.164)
Pirmez Creek	13,382 (0.152)	***16,013 (0.246)***	25,314 (0.090)
Millburn Creek	***4,723 (0.818)***	2,837 (0.126)	625 (0.192)
Springbank Creek	***507 (0.417)***	***452 (0.210)***	277 (0.148)
Lott Creek	***3,446 (0.288)***	5,924 (0.084)	12,602 (0.100)

Redwood Meadows and Sarcee Bridge not sampled in 1999 and 2000; hyphen indicates insufficient data to prepare mass flux estimate.

larger amount of deposition occurred in the reach downstream between Twin Bridges and Sarcee Bridge (-58,752 tonnes). These findings suggest that the spatial pattern of TSS loading and deposition change considerably from year to year depending on river flow. The slope of the Elbow River bed declines near Twin Bridges (Hudson, 1983; presented as Figure 2 of Beers and Sosiak, 1993). River velocity presumably declines as a result, which would contribute to deposition of TSS in this reach.

Although significant deposition of TSS occurred each year immediately downstream of either the Glencoe GCC or Twin Bridges, from sources further upstream, appreciable TSS loading from nonpoint sources occurred in the reach above Weaselhead Bridge in 2000 and 2002 (Figure 33). The channel in this reach is highly sinuous, and very unstable banks were observed during the aerial survey at three locations between Discovery Ridge and Weaselhead Bridge (Map 3). Furthermore, there are several storm sewer outfalls in this reach, which probably contribute TSS during storm events.

TSS loadings from tributaries were very small each year compared to mainstem sources along the Elbow River. In 2000, Lott Creek contributed only 0.8% of the total TSS load in the lower reach, and in 2002, although the load of Bragg Creek was estimated at 196 tonnes of TSS, this was only 0.4% of the total load in the upper reach (Table 13). Because these tributary TSS sources are so small compared to nonpoint sources, TSS mass from tributaries is not visible on Figure 33.

Total Suspended Solids Temporal Trends

In the high flow year of 2002, elevated TSS concentrations were recorded at the Glencoe GCC, and a significant increasing trend in TSS concentration was also evident at this site (Table 14, Figure 34). This clearly indicates an area of concern. Riprap has been installed at the Glencoe GCC site and extensive bank erosion occurred there in 2002 (Map 3). In contrast, peak TSS concentrations along the Elbow River occurred in 1999 and 2000 at the Weaselhead Bridge, which suggests that the main sources of TSS were downstream of Twin Bridges during years of lower flows (Figure 31).

Because TSS and turbidity are both strongly and significantly correlated with flow (Spearman $\rho = 0.538$ and $\rho = 0.679$, respectively, both $P<0.05$), turbidity levels declined at Twin Bridges when flows were below average in 2000 and 2001 (Figure 2). Similarly, a significant decline in TSS has occurred in the Elbow River following the recent years of below average flow at the site upstream from Bragg Creek (Figure 34), above which there are few impacts on the channel from human activities. Although turbidity levels at the Twin Bridges site remained high during high flows, the trend previously identified at this site (Sosiak, 1999) was not statistically significant after the recent years of below average flow (Figure 35). However, a significant increasing trend in turbidity during 1988-2002 was detected at Weaselhead Bridge (Table 14, Figure 35).

Table 14. Significant monotonic trends for total suspended solids and turbidity in the Elbow River and its major tributaries.

		Sen Slope (units/yr) for significant trends (seasonal kendall tau test, except as indicated[a])	
Sites	Time Period/ (yrs of data)	Total Suspended Solids µg/L	Turbidity, NTU
Elbow River Mainstem			
Cobble Flats	1988-2002 (3, 3)	-	-
Above Bragg Creek	1979-2002 (5, 5)	**-149.56[a]**	NS
Highway 22 Bridge	1979-2002 (8, 5)	NS	NS
Glencoe GCC	1988-2002 (6, 2)	**+412.18**	-
Twin Bridges	1979-2002 (8, 14)	NS	NS
Weaselhead Bridge	1988-2002 (8, 13)	NS	**+0.51**
Upper Glenmore Reservoir	1982-2002 (0, 17)	-	NS
Glenmore Raw Intake	1991-2002 (6, 12)	-	NS
Elbow River at 9th Ave.	1974-2002 (14, 13)	NS	NS
Elbow River Tributaries			
Little Elbow River	1978-2002 (5, 5)	NS[a]	NS[a]
McLean Creek	1978-2002 (6, 6)	NS	NS
Bragg Creek	1988-2002 (6, 4)	NS[a]	NS[a]
Pirmez Creek	1989-2002 (4, 0)	NS[a]	-
Millburn Creek	1989-2002 (4, 0)	NS[a]	-
Springbank Creek	1989-2002 (3, 0)	NS[a]	-
Lott Creek	1988-2002 (6, 4)	NS[a]	NS[a]

[a] Kendall tau test (non-seasonal); NS = no statistically significant trend detected; hyphen indicates insufficient historical data for trend analysis (N < 4 yrs).

Table 13. Mass flux for total suspended solids (kg per sampling season, coefficients of variation in parentheses) for the Elbow River and its major tributaries between Bragg Creek and Weaselhead Bridge. Less reliable estimates (CV >0.2) are in bold italics.

	Total Suspend Solids, kg		
Sites	**1999**	**2000**	**2002**
Elbow River			
Above Bragg Creek	***952,476 (0.299)***	137,335 (0.122)	57,298,720 (0.181)
Redwood Meadows			
Highway 22 Bridge	1,244,624 (0.199)	264,173 (0.142)	101,071,100 (0.172)
Glencoe GCC	1,763,821 (0.176)	573,865 (0.162)	92,455,680 (0.129)
Twin Bridges	2,822,856 (0.175)	394,934 (0.083)	105,647,600 (0.130)
Sarcee Bridge			46,907,900 (0.157)
Weaselhead Bridge	***3,618,437 (0.365)***	1,126,208 (0.165)	63,496,990 (0.092)
Elbow River Tributaries			
Bragg Creek	***31,535 (0.401)***	***3,704 (0.244)***	196,353 (0.164)
Pirmez Creek	13,382 (0.152)	***16,013 (0.246)***	25,314 (0.090)
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Redwood Meadows and Sarcee Bridge not sampled in 1999 and 2000; hyphen indicates insufficient data to prepare mass flux estimate

larger amount of deposition occurred in the reach downstream between Twin Bridges and Sarcee Bridge (-58,752 tonnes). These findings suggest that the spatial pattern of TSS loading and deposition change considerably from year to year depending on river flow. The slope of the Elbow River bed declines near Twin Bridges (Hudson, 1983; presented as Figure 2 of Beers and Sosiak, 1993). River velocity presumably declines as a result, which would contribute to deposition of TSS in this reach.

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Total Suspended Solids Temporal Trends

In the high flow year of 2002, elevated TSS concentrations were recorded at the Glencoe GCC, and a significant increasing trend in TSS concentration was also evident at this site (Table 14, Figure 34). This clearly indicates an area of concern. Riprap has been installed at the Glencoe GCC site and extensive bank erosion occurred there in 2002 (Map 3). In contrast, peak TSS concentrations along the Elbow River occurred in 1999 and 2000 at the Weaselhead Bridge, which suggests that the main sources of TSS were downstream of Twin Bridges during years of lower flows (Figure 31).

Because TSS and turbidity are both strongly and significantly correlated with flow (Spearman $\rho = 0.538$ and $\rho = 0.679$, respectively, both $P < 0.05$), turbidity levels declined at Twin Bridges when flows were below average in 2000 and 2001 (Figure 2). Similarly, a significant decline in TSS has occurred in the Elbow River following the recent years of below average flow at the site upstream from Bragg Creek (Figure 34), above which there are few impacts on the channel from human activities. Although turbidity levels at the Twin Bridges site remained high during high flows, the trend previously identified at this site (Sosiak, 1999) was not statistically significant after the recent years of below average flow (Figure 35). However, a significant increasing trend in turbidity during 1988-2002 was detected at Weaselhead Bridge (Table 14, Figure 35).

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		Sen Slope (units/yr) for significant trends (seasonal kendall tau test, except as indicated[a])	
Sites	Time Period/ (yrs of data)	Total Suspended Solids µg/L	Turbidity NTU
Elbow River Mainstem			
Cobble Flats	1988-2002 (3, 3)		
Above Bragg Creek	1979-2002 (5, 5)	**-149.56[a]**	NS
Highway 22 Bridge	1979-2002 (8, 5)	NS	NS
Glencoe GCC	1988-2002 (6, 2)	**+412.18**	
Twin Bridges	1979-2002 (8, 14)	NS	NS
Weaselhead Bridge	1988-2002 (8, 13)	NS	**+0.51**
Upper Glenmore Reservoir	1982-2002 (0, 17)		NS
Glenmore Raw Intake	1991-2002 (6, 12)		NS
Elbow River at 9th Ave.	1974-2002 (14, 13)	NS	NS
Elbow River Tributaries			
Little Elbow River	1978-2002 (5, 5)	NS[a]	NS[a]
McLean Creek	1978-2002 (6, 6)	NS	NS
Bragg Creek	1988-2002 (6, 4)	NS[a]	NS[a]
Pirmez Creek	1989-2002 (4, 0)	NS[a]	
Millburn Creek	1989-2002 (4, 0)	NS[a]	
Springbank Creek	1989-2002 (3, 0)	NS[a]	
Lott Creek	1988-2002 (6, 4)	NS[a]	NS[a]

[a] Kendall tau test (non-seasonal); NS = no statistically significant trend detected; hyphen indicates insufficient historical data for trend analysis (N < 4 yrs)

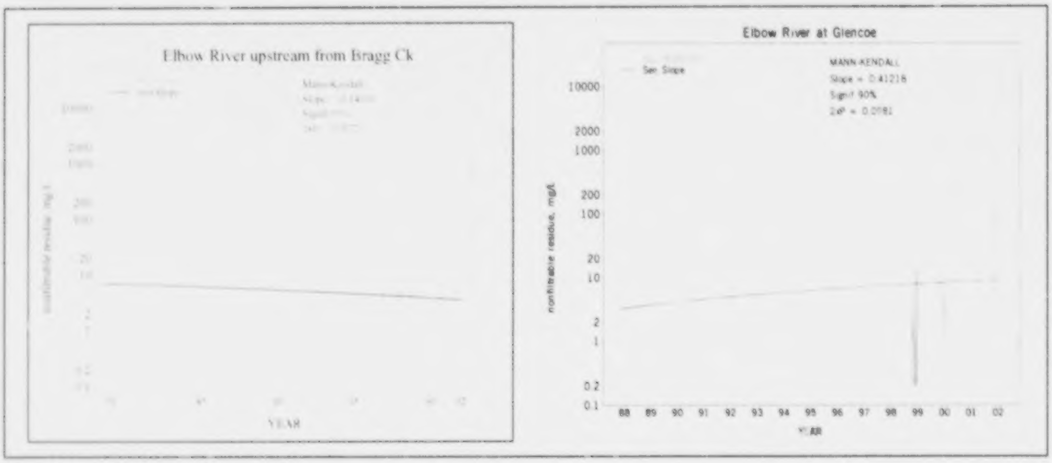

Figure 34. TSS (as nonfilterable residue) in the Elbow River upstream from Bragg Creek, 1988-2002, and the Elbow River at Glencoe, 1988-2002.

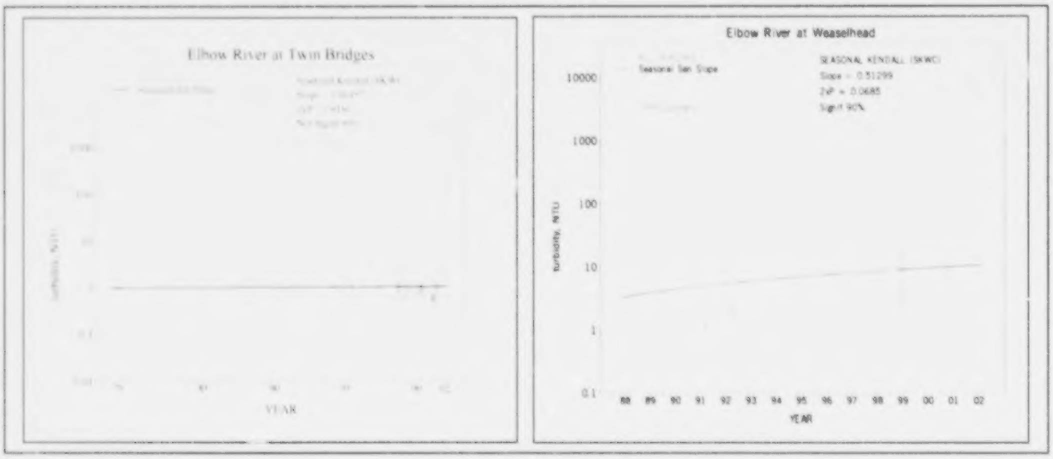

Figure 35. Turbidity in the Elbow River at Twin Bridges, 1979-2002, and the Elbow River at Weaselhead Bridge, 1988-2002.

Coliform Bacteria

Coliform bacteria, which include a diverse assemblage of both enteric and free-living organisms, are comprised of the total coliform group, the family of fecal coliforms, and the important species *Escherichia coli* (*E. coli*). These last two are organisms typically found within the digestive systems of warm-blooded animals, and accordingly, the presence of either of these can indicate the presence of fecal wastes in surface waters, suggesting that other pathogenic, or disease-causing, bacteria, viruses and/or protozoa may be present (APHA, 1998; CCME, 2003). Since the total coliform test detects both enteric and free-living coliform organisms, high counts are not necessarily indicative of fecal contamination. The City of Calgary continues total coliform testing in the Elbow River to document background levels in raw water supplies, and through the water treatment process and distribution system, but Alberta Environment no longer conducts this test routinely on surface water samples.

Fecal coliform bacteria have been used historically to indicate potential microbial risk because they are relatively easy to measure, and guidelines are available for treated drinking water, water-contact recreation and other uses (CCME, 2003). However, the use of the fecal coliform group as an indicator is falling out of favour because of its poor correlation to human health risk (CCME, 2003). Accordingly, organisms such as *E. coli* that provide a more reliable indication of health risk are being used more widely.

The presence of *E. coli*, one species in the fecal coliform group, is a definite indicator of the presence of fecal contamination (APHA, 1998). *E. coli* are generally considered the preferred indicator for fecal contamination. Other species that are detected by the fecal coliform test, such as *Kliebsella*, *Enterobacter* or *Citrobacter*, are not restricted to feces and can occur naturally on vegetation or soils (Health Canada, 1996). These other organisms complicate the use of the fecal coliform test to assess fecal contamination.

E. coli originate from the wastes of any warm-blooded animal, including humans, livestock such as cattle, horses, hogs, sheep and poultry, and wildlife such as beaver, muskrat, deer, elk, and waterfowl. *E. coli* from livestock manure storage systems, lagoons, or land application of manure may reach surface waters from direct runoff or via groundwater flow. Human wastes can enter water from improperly functioning or maintained septic systems, direct discharge from sewage systems, or from combined or cross-connected storm sewers. Wastes from domestic animals and urban wildlife may also be washed off and discharged through storm outfalls.

Fecal coliforms and *E. coli* can affect the suitability of water for irrigation, contact recreation and drinking water. The tentative irrigation guideline for fecal coliforms is intended to protect consumers of irrigated produce that is typically eaten raw.

Fecal Coliforms

Elbow River Sites

Fecal coliform counts did not vary significantly among sites for any year ($P>0.05$), although a slight, but consistent longitudinal trend in fecal coliform counts was apparent (Figure 36). Fecal coliforms increased from the site at the Elbow River above Bragg Creek (medians range: 4 to 8 per 100 mL in 1999 and 2002, respectively) to the highest counts at the Weaselhead Bridge site (medians range: 10 to 18 per 100 mL in 1999 and 2002, respectively). Fecal coliforms were not sampled in 2001.

Seasonally, peak fecal coliform numbers were usually found in May or June of each year. In 1999, peak coliform numbers ranged from 30 to 530 per 100 mL (Figure 36) from late April to early June, well before the runoff from mountain snowmelt. In 2000, the highest counts among all mainstem sites were at Hwy 22 Bridge (98 per 100 mL) and Weaselhead (370 per 100 mL), both occurring in mid to late May. Overall peaks were lower in 2002, a year with greater river flow, as maximum values ranged from 50 per 100 mL above Bragg Creek in mid-May to 150 per 100 mL at the Weaselhead Bridge on June 14.

Exceedance of the Canadian Water Quality Guidelines of 400 per 100 mL (resampling guideline for recreation) and 100 per 100 mL

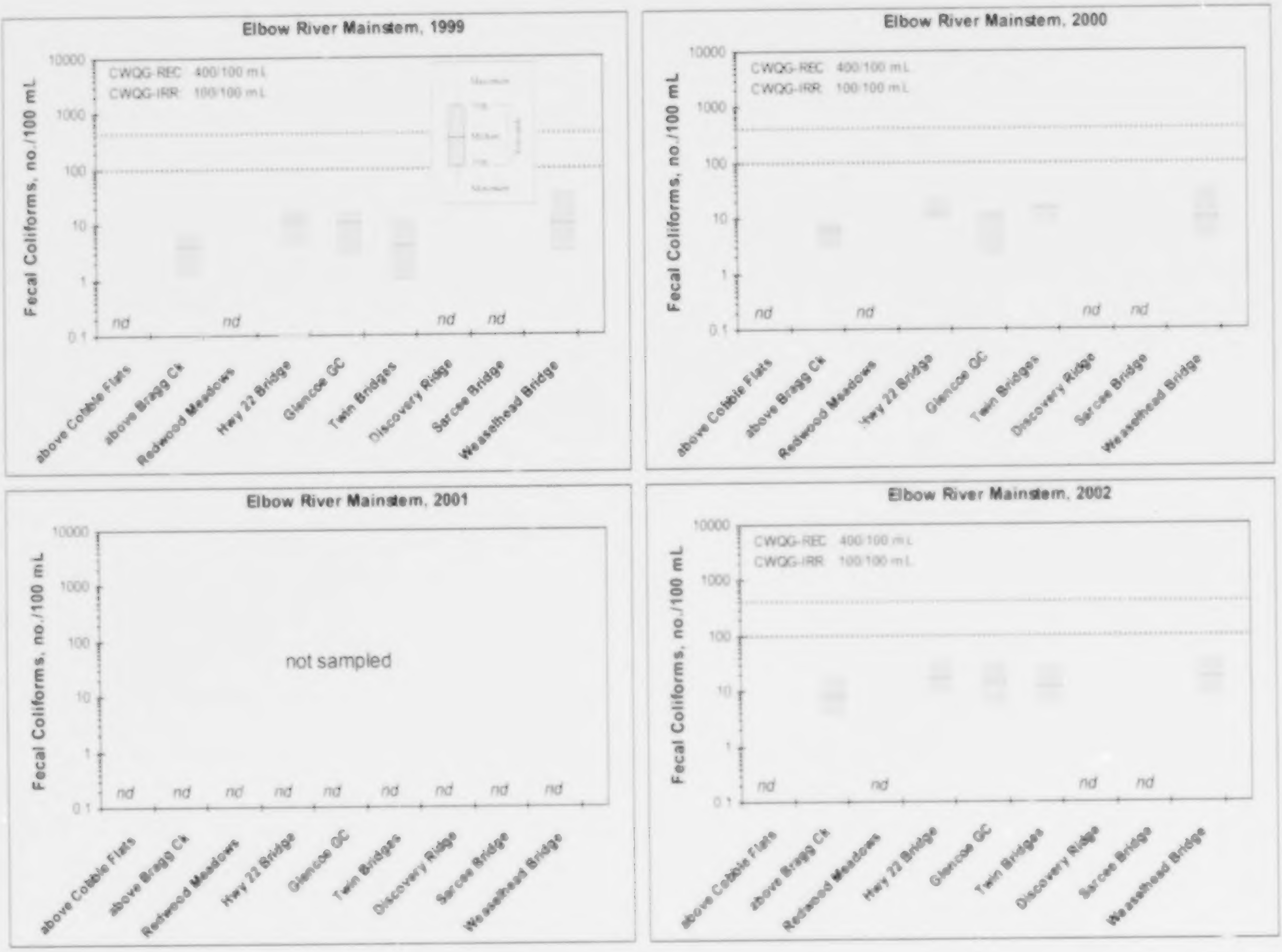

Figure 36. Fecal coliforms at Elbow River mainstem sites: April to August, 1999, 2000 and 2002 (*nd=no data*).

(irrigation) was rare. Fecal coliforms only exceeded the recreation guideline once at the Weaselhead Bridge site: 530 per 100 mL in June, 1999; two other samples exceeded the irrigation guideline: 370 per 100 mL in May, 2000, and 150 per 100 mL in June, 2002.

Elbow River Tributary Sites

Differences among tributaries were observed in fecal coliform counts for all years sampled ($P<0.05$), with either Pirmez or Millburn Creeks usually exhibiting the greatest numbers (Figure 37). In 1999, median fecal coliform numbers of 275 per 100 mL at Pirmez Creek were significantly greater than at Bragg Creek, Springbank Creek, and Lott Creek ($P<0.05$). In 2000, Millburn Creek had the highest median counts for the season with 590 per 100 mL, significantly greater than Lott Creek ($P<0.05$). And in 2002, Pirmez Creek had the highest median fecal coliform densities among tributaries, with 210 per 100 mL, which was significantly higher than Millburn, Springbank and Lott Creeks ($P<0.05$). In 1999 and 2002, fecal coliform numbers were significantly lower in Lott Creek compared to all other tributaries ($P<0.05$), and in 2000 counts in Lott Creek were lower than Millburn Creek ($P<0.05$). Fecal coliforms were not sampled in 2001. In 1999 and 2000, tributaries other than Lott Creek had higher fecal coliform counts than the Elbow River.

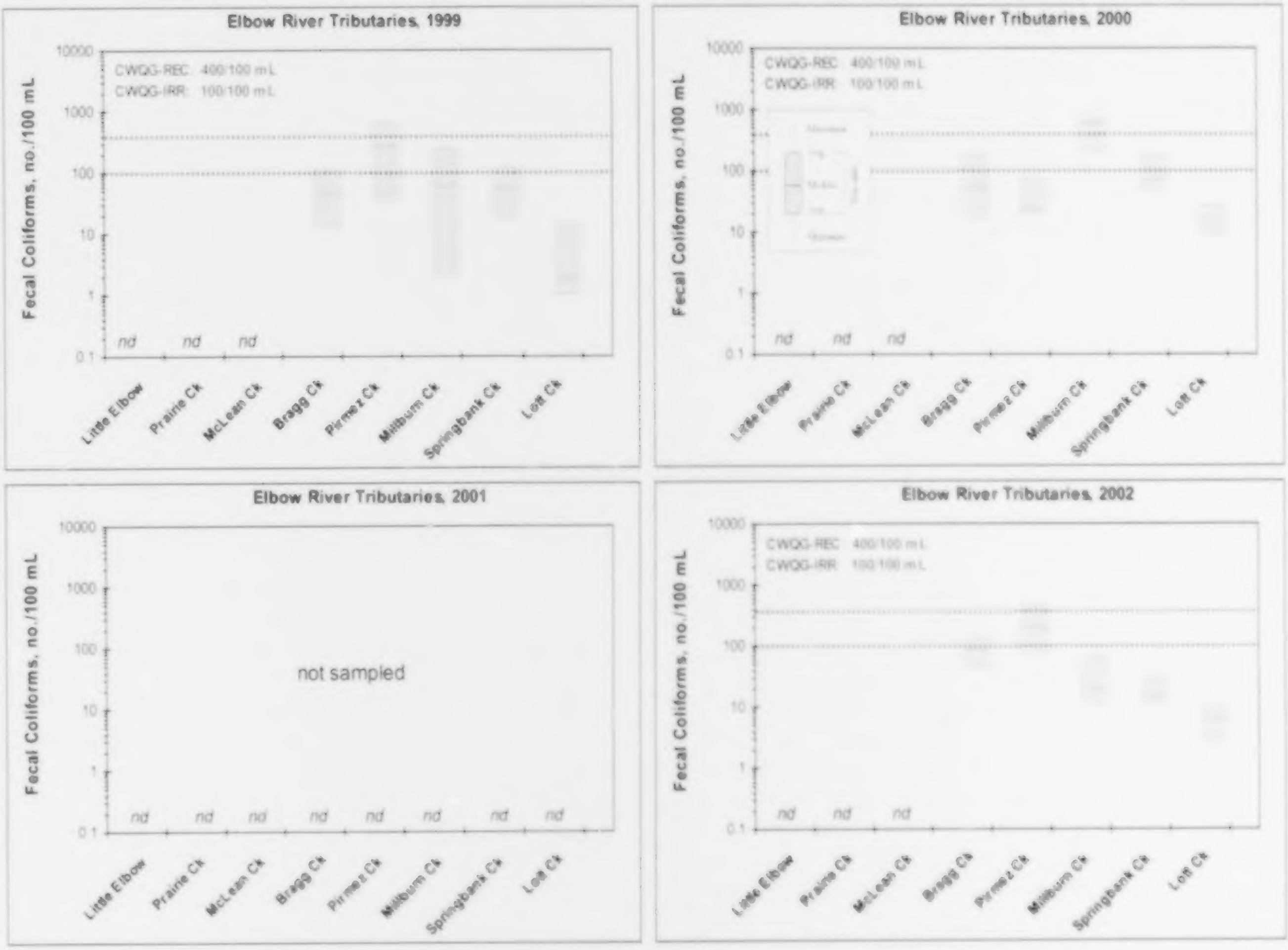

Figure 37. Fecal coliforms at Elbow River tributary sites: March to September, 1999, 2000, and 2002 (*nd=no data*).

Seasonally, Bragg Creek and Pirmez Creek exhibited higher fecal coliform numbers earlier in the sampling season, during April to June, whereas Millburn and Springbank Creeks displayed higher levels later in the season, during July and August. In 1999 and 2002, maximum fecal coliform numbers among all tributaries were found at Pirmez Creek at 1700 per 100 mL and 2300 per 100 mL in April and May respectively, and at Millburn Creek in 2001, with an overall maximum of 4100 per 100 mL in mid-July (Figure 37).

Fecal coliforms most often exceeded water quality guidelines in Pirmez and Millburn Creeks. Overall, fecal coliforms in Pirmez Creek exceeded the Canadian Water Quality irrigation guideline in 65% of samples, and the recreational guideline in 35% of samples. Millburn Creek samples exceeded the irrigation and recreational guideline 64% and 28% of the time, respectively. A lower rate of exceedance occurred in Bragg Creek, (2% of samples exceeding the recreational guideline, and 37% over the irrigation guideline), and Springbank Creek with 12% and 29%, respectively. Only 1 sample from Lott Creek exceeded the irrigation guideline. These findings indicate that water quality for these two uses is often impaired in both Pirmez and Millburn Creeks.

Escherichia coli

Elbow River Sites

E. coli levels in the Elbow River generally increased from upstream to downstream sites in all years (Figure 38). Median *E. coli* densities were always lowest at the Cobble Flats site, ranging from 2 per 100 mL in 1999 and 2002 to 6 per 100 mL in 2001. Intermediate *E. coli* levels were usually observed at the Highway 22 site, with medians of 5 to 7 *E. coli* per 100 mL in all years. For most years, *E. coli* levels were highest at the Weaselhead site, with medians varying from 16 to 17 per 100 mL in 1999 and 2000, to 30 per 100 mL in 2001, and 23 per 100 mL in 2002.

In all years, *E. coli* numbers differed significantly among sites in ($P<0.05$). In 1999, *E. coli* at the Weaselhead Bridge (median 16 per 100 mL) was significantly greater than at the Elbow River sites in the upper watershed at Cobble Flats and above Bragg Creek (range of medians from 2-3 per 100 mL), and the mid-reach site at Glencoe GCC (median 4 *E. coli* per 100 mL) (Figure 38). In 2000, *E. coli* levels of 17 per 100 mL at Weaselhead Bridge were significantly greater than above Bragg Creek and Glencoe GCC (medians from 1 to 4 per 100 mL). *E. coli* medians at the Weaselhead, were 30 and 23 per 100 mL in 2001 and 2002, respectively, and were significantly greater than the Highway 22 Bridge site ($P<0.05$). In 2002, Sarcee Bridge exhibited the highest *E. coli* levels among all sites, with a seasonal median of 39 per 100 mL, significantly greater than the mainstem sites above Twin Bridges ($P<0.05$).

Among reaches, the greatest increase in median *E. coli* densities was found in the Elbow River between the Glencoe GCC and the Weaselhead Bridge. An increase of 12 *E. coli* per 100 mL was observed in 1999 and 2002, and 16 per 100 mL in 2001 (Figure 38), clearly indicating an area of bacterial load. In contrast, median *E. coli* declined from Redwood Meadows to Hwy 22 Bridge in 1999 and 2001 by 4 per 100 mL, and by 6 per 100 mL from the Hwy 22 Bridge to the Glencoe GCC in 2000.

Seasonally, maximum *E. coli* densities generally occurred during the June/July mountain snowmelt runoff. In both 2001 and 2002, for example, all *E. coli* maximums for all sites were recorded in June during the mountain snowmelt period. On occasion, however, high *E. coli* numbers were found outside the primary runoff period. In 1999, a maximum *E. coli* density of 744 per 100 mL was recorded at the Weaselhead site (Figure 38) in April. Moreover, in 2000, peak *E. coli* numbers at Twin Bridges and Weaselhead occurred after the June runoff in mid-July. Earlier peaks in *E. coli* counts could be related to local snowmelt; whereas peaks occurring later in the season may be associated with summer precipitation and runoff events.

Over the four-year period, there were only three instances of Elbow River samples exceeding the Canadian Water Quality Guidelines for recreation for *E. coli* (0.5% exceedance rate): on April 10 and June 3, 1999 values of 744 and 510 per 100 mL, respectively, were recorded at the Weaselhead Bridge site; and on June 17, 2002 a value of 613 per 100 mL was recorded at the Sarcee Bridge site.

Elbow River Tributary Sites

E. coli levels in the Elbow River tributary sites were highly variable among sites and among years (Figure 39). In most years, median *E. coli* densities at Bragg Creek, Pirmez Creek, Millburn Creek and Springbank Creek were the highest among tributaries, varying from 20 to 55 per 100 mL in 1999, 13 to 360 per 100 mL in 2000 and 14 to 63 per 100 mL. *E. coli* counts at the Little Elbow River and Lott Creek were generally low each year, with median levels of 1 to 2 per 100 mL at the Little Elbow and 3 to 10 per 100 mL at Lott Creek, significantly less than the other tributaries ($P<0.05$).

There was no consistent pattern of peak *E. coli* counts during the season at most tributary sites, as maximum numbers were generally observed at different times. However, Pirmez Creek *E. coli* counts were usually highest early in the season, either in April or May, with counts ranging from 710 per 100 mL in 2000, to 1300 per 100 mL in both 1999 and 2002 (Figure 39). Additionally, Millburn Creek, which had maximum counts from 350 to 3200 per 100 mL, generally peaked later in the season in August or September.

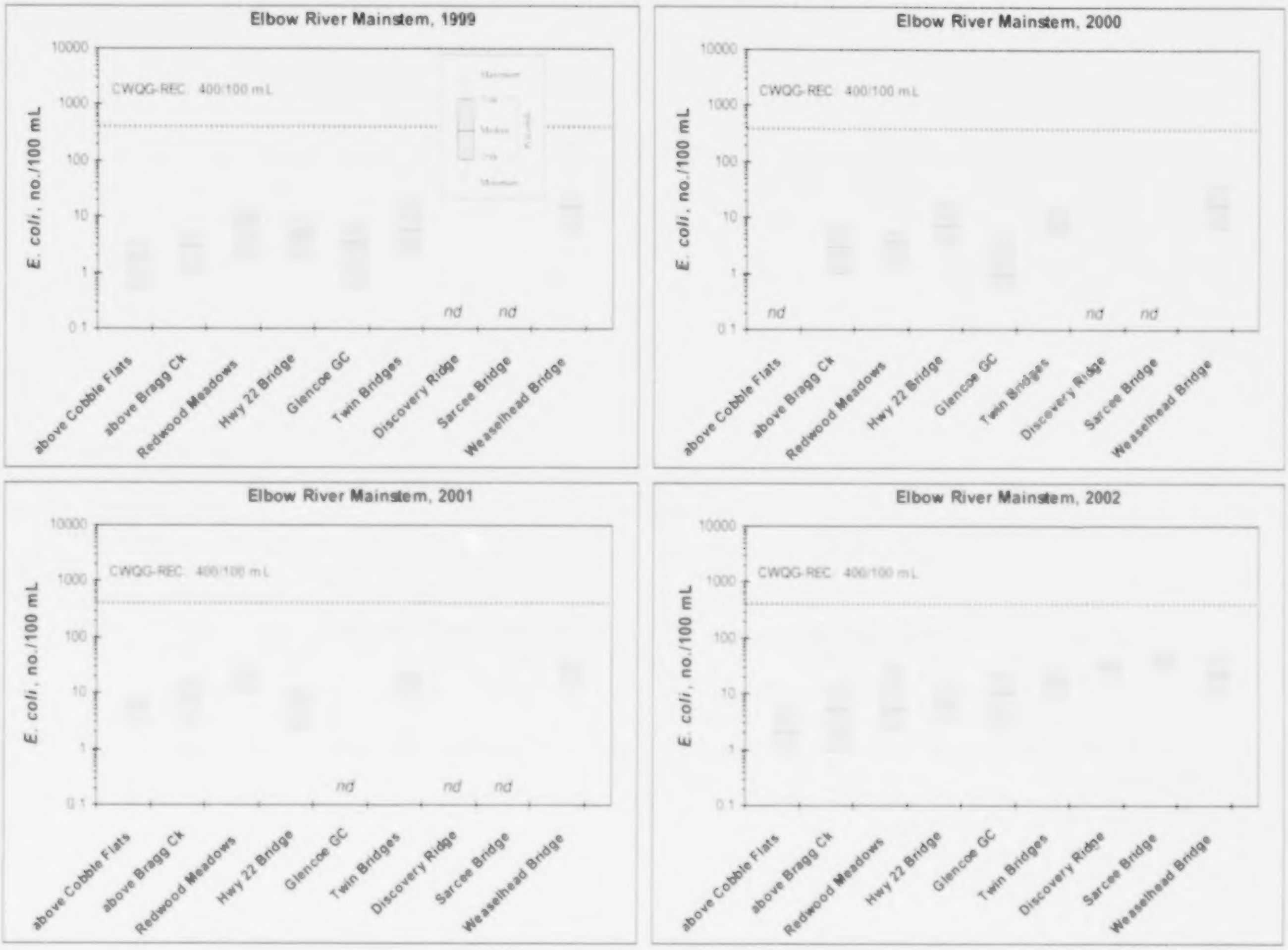

Figure 38. *E.coli* at Elbow River mainstem sites: March to September, 1999-2002 (*nd=no data*).

E. coli counts mainly exceeded the recreation guidelines in Pirmez and Millburn Creeks. Among all years, 21% of samples in both Pirmez and Millburn Creeks (9 in 43 samples for Pirmez, and 8 in 39 samples for Millburn) exceeded the recreation guideline. The corresponding rate for Springbank Creek was 7% (5 in 73 samples), and for Prairie Creek it was 6% (1 in 18 samples). Only one in 75 samples exceeded this guideline in Bragg Creek.

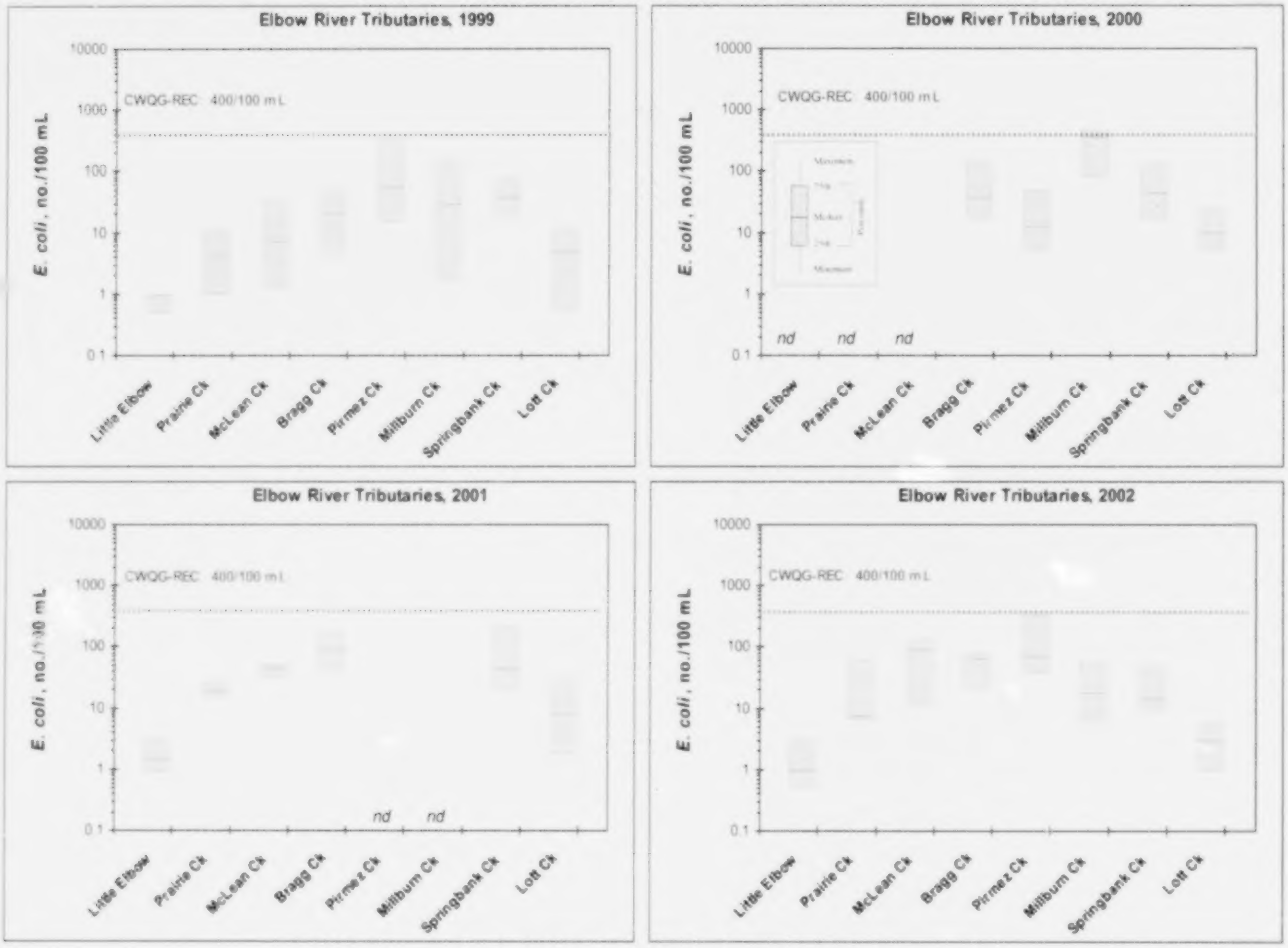

Figure 39. *E. coli* at Elbow River tributary sites: March to September, 1999-2002 (*nd=no data*).

Coliform Bacteria Temporal Trends

Over the period of record, 1979 to 2002, large and significant increasing trends in total coliform counts were found in results for the Elbow River at both Twin Bridges and the Weaselhead Bridge (Table 15). During this same period, there was a significant increasing trend in fecal coliforms at the Twin Bridges site alone (Figure 40, Table 15), confirming results from a previous analysis on a shorter time series (Sosiak, 1999). *E. coli* have not been sampled enough years to reliably determine long term trends at most locations. In addition, increasing trends in total coliforms were also detected in the Elbow River at Cobble Flats, the Little Elbow River, McLean Creek, and Lott Creek. However, the number of years available for analysis at these locations was limited (*N*: 4-6), and may be more influenced by sampling during recent low-flow years.

These findings indicate that the greatest impact in coliform levels occurred between the Glencoe GCC and Weaselhead Bridge, but the pattern was somewhat different for the different types of coliform tests from year to year. The greatest change on *E. coli* levels in the Elbow River occurred in the reach from the Glencoe GCC to Twin Bridges. Both agriculture and extensive residential development occur along this reach, and could contribute to increasing fecal coliform counts at Twin Bridges. The highest *E. coli* counts were in the lower reach of the Elbow River, at the Weaselhead Bridge from 1999 to 2001 and at Sarcee Bridge in 2002. Storm sewers from urban runoff discharging to this reach could account for these levels.

The large increasing trends in total coliform counts at Twin Bridges and Weaselhead Bridge (Table 15) confirm that the level of coliform bacteria has generally increased in the reach from the Glencoe GCC to the Weaselhead Bridge. However, much of the increase in total coliforms could be due to harmless naturally occurring organisms rather than fecal coliforms from humans or animals. The rate of increase in fecal coliforms (Sen slope: +0.47 coliforms/year) was much lower than the rates for total coliforms at Twin Bridges and Weaselhead Bridge (Sen slope: +6.12, +39.61 coliforms/year, respectively). This suggests that organisms other than fecal coliforms contributed to much of the increase in total coliforms.

Table 15. Significant monotonic trends for total and fecal coliforms in the Elbow River and its major tributaries.

		Sen Slope (units/yr) for significant trends (seasonal kendall tau test, except as indicated[a])	
Sites	Time Period/ (yrs of data)	Total Coliforms no./100 mL	Fecal Coliforms no./100 mL
Elbow River Mainstem			
Cobble Flats	1988-2002 (4, 1)	**+1.08**	–
Above Bragg Creek	1979-2002 (5, 4)	NS	NS
Highway 22 Bridge	1979-2002 (7, 6)	NS	NS
Glencoe GCC	1988-2002 (1, 5)	–	NS
Twin Bridges	1979-2002 (13, 15)	**+6.12**	**+0.47**
Weaselhead Bridge	1988-2002 (8, 10)	**+39.61**	NS[a]
Upper Glenmore Reservoir	1982-2002 (0, 0)	–	–
Glenmore Raw Intake	1989-2002 (14, 7)	NS	NS[b]
Elbow River at 9th Ave	1994-2002 (0, 9)	–	NS
Elbow River Tributaries			
Little Elbow River	1978-2002 (6, 3)	**+0.28**	–
McLean Creek	1978-2002 (7, 4)	**+30.16**	–[c]
Bragg Creek	1988-2002 (6, 5)	NS	NS
Pirmez Creek	1989-2002 (2, 3)	–	–[d]
Millburn Creek	1999-2002 (0, 3)	–	–
Springbank Creek	1989-2002 (0, 3)	–	–
Lott Creek	1986-2002 (6, 5)	**+71.74**	NS

[a] Kendall tau test (non-seasonal); [b] sampled 1989-1995; [c] sampled 1978-1989; [d] sampled 1999-2002; NS = no statistically significant trend detected; hyphen indicates insufficient historical data for trend analysis (N < 4 yrs).

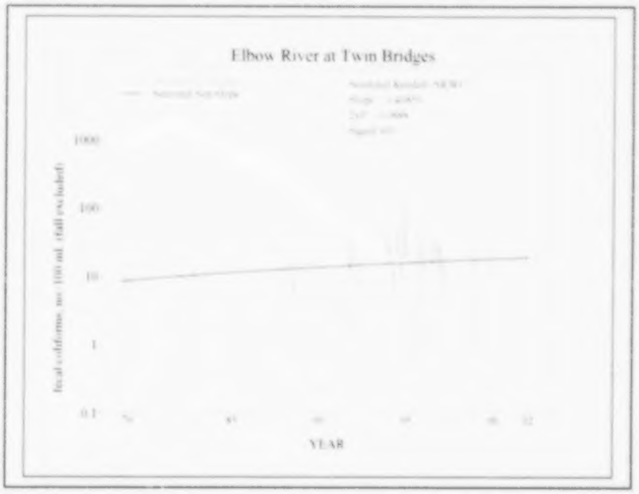

Figure 40. Fecal coliforms in the Elbow River at Twin Bridges, 1979-2002.

Coliform Bacteria Temporal Trends

Over the period of record, 1979 to 2002, large and significant increasing trends in total coliform counts were found in results for the Elbow River at both Twin Bridges and the Weaselhead Bridge (Table 15). During this same period, there was a significant increasing trend in fecal coliforms at the Twin Bridges site alone (Figure 40, Table 15), confirming results from a previous analysis on a shorter time series (Sosiak, 1999). *E. coli* have not been sampled enough years to reliably determine long term trends at most locations. In addition, increasing trends in total coliforms were also detected in the Elbow River at Cobble Flats, the Little Elbow River, McLean Creek, and Lott Creek. However, the number of years available for analysis at these locations was limited (*N*: 4-6), and may be more influenced by sampling during recent low-flow years.

These findings indicate that the greatest impact in coliform levels occurred between the Glencoe GCC and Weaselhead Bridge, but the pattern was somewhat different for the different types of coliform tests from year to year. The greatest change on *E. coli* levels in the Elbow River occurred in the reach from the Glencoe GCC to Twin Bridges. Both agriculture and extensive residential development occur along this reach, and could contribute to increasing fecal coliform counts at Twin Bridges. The highest *E. coli* counts were in the lower reach of the Elbow River, at the Weaselhead Bridge from 1999 to 2001 and at Sarcee Bridge in 2002. Storm sewers from urban runoff discharging to this reach could account for these levels.

The large increasing trends in total coliform counts at Twin Bridges and Weaselhead Bridge (Table 15) confirm that the level of coliform bacteria has generally increased in the reach from the Glencoe GCC to the Weaselhead Bridge. However, much of the increase in total coliforms could be due to harmless naturally occurring organisms rather than fecal coliforms from humans or animals. The rate of increase in fecal coliforms (Sen slope: +0.47 coliforms/year) was much lower than the rates for total coliforms at Twin Bridges and Weaselhead Bridge (Sen slope: +6.12, +39.61 coliforms/year, respectively). This suggests that organisms other than fecal coliforms contributed to much of the increase in total coliforms.

Table 15. Significant monotonic trends for total and fecal coliforms in the Elbow River and its major tributaries.

		Sen Slope (units/yr) for significant trends (seasonal kendall tau test, except as indicated[a])	
Sites	Time Period/ (yrs of data)	Total Coliforms no./100 mL	Fecal Coliforms no./100 mL
Elbow River Mainstem			
Cobble Flats	1988-2002 (4, 1)	**+1.08**	
Above Bragg Creek	1979-2002 (5, 4)	NS	NS
Highway 22 Bridge	1979-2002 (7, 6)	NS	NS
Glencoe GCC	1988-2002 (1, 5)		NS
Twin Bridges	1979-2002 (13, 15)	**+6.12**	**+0.47**
Weaselhead Bridge	1988-2002 (8, 10)	**+39.61**	NS
Upper Glenmore Reservoir	1982-2002 (0, 0)		
Glenmore Raw Intake	1989-2002 (14, 7)	NS	NS
Elbow River at 9th Ave	1994-2002 (0, 9)		NS
Elbow River Tributaries			
Little Elbow River	1978-2002 (6, 3)	**+0.28**	
McLean Creek	1978-2002 (7, 4)	**+30.16**	
Bragg Creek	1988-2002 (6, 5)	NS	NS
Pirmez Creek	1989-2002 (2, 3)		
Millburn Creek	1999-2002 (0, 3)		
Springbank Creek	1989-2002 (0, 3)		
Lott Creek	1986-2002 (6, 5)	**+71.74**	NS

[a] Kendall tau test (non-seasonal); sampled 1989-1995; sampled 1978-1989; sampled 1999-2002; NS = no statistically significant trend detected; hyphen indicates insufficient historical data for trend analysis (N < 4 yrs)

Figure 40. Fecal coliforms in the Elbow River at Twin Bridges, 1979-2002.

Bacterial Source Tracking

Ruminant markers were found on at least one trip at all sampling locations except on Lott Creek, the headwaters of Pirmez Creek, and Weaselhead Bridge (Table 16). These results confirm that ruminant animals are present upstream from all locations where such markers were found, even in the headwaters in the Elbow River at Cobble Flats. These ruminants could be either cattle or ruminant wildlife such as sheep or deer. This testing does not allow one to identify individual species. Because the Lott Creek basin has been largely converted to residential development, there should now be few ruminants in this basin, and no ruminant markers were found. The site in the headwaters of Pirmez Creek is largely forested, with few signs of cattle upstream from the sampling location. Ruminants could still be upstream from this headwaters site, but seldom have direct access to the creek.

Enterococci are exclusively associated with fecal wastes (CCME, 2003). Enterococci were found during the single round of sampling at all sites where ruminant markers were found at least once during the sampling season, except for Cobble Flats where there are few human impacts. However, enterococci were not found or were very low in number ($\leq$ 5) at all sites where ruminant markers were absent (both Lott Creek locations, and the headwaters of Pirmez Creek). This correlation was not statistically significant (Spearman $\rho = -0.217$, $P>0.05$), perhaps because the ruminant markers were not consistently found at a given location. The sole exceptions to this pattern were Weaselhead Bridge, Lott Creek (both sites), and Pirmez Creek (headwaters) where ruminant markers were never found in 2003, as discussed below. Enterococci only exceeded the Canadian Water Quality resampling guideline for recreation and aesthetics (70 per 100 mL) on one occasion at the site on Millburn Creek near the mouth (Table 16).

Fecal coliforms and *E. coli* counts also tended to be high where ruminant markers were found, but these variables were also not significantly correlated with ruminant (Spearman $\rho = 0.132$ and $\rho = 0.096$, respectively, both $P>0.05$). However, no ruminant markers were found at sites such as the Lott Creek sites, which still had moderately high fecal bacteria counts. Animals that are not ruminants, such as birds, could also contribute fecal bacteria to some areas, and other harmless organisms can be detected by the fecal coliform test.

No human markers were found in any of the 57 samples from 16 locations, although this marker was found in the raw sewage sample from the Elbow basin (Table 16). This indicates that there was little or no movement of human sewage to these water bodies, for example leachate from septic fields, during the sampling period. Leachate could be more likely to migrate during the winter, if more movement of groundwater to the river occurs. A ruminant marker was also found in the raw sewage sample. The composite sewage sample included a septic tank at an animal hospital, which could account for the ruminant marker.

Failure to detect a ruminant or human marker does not imply a complete absence of such fecal pollution upstream. For example, no ruminant markers were detected in the Elbow River at Weaselhead Bridge, which is downstream from all the other sampling sites, including those where ruminants were repeatedly found. Ruminant markers could be present, but not detected because of simple dilution. Elbow River flows were generally highest at Weaselhead Bridge. Furthermore, ruminants may not have direct or frequent access to a given reach, and drier areas may have less runoff and movement of fecal material to the sampled reaches than wetter areas. Such factors must influence the success in detecting markers, as there was no site at which ruminant markers were always found.

Salmonella was found in the sample from Springbank Creek at Range Road 40 on September 10, 2003. Otherwise, none of the human pathogens for which samples were tested in the bacterial source tracking study was found at any site (Table 16). Accordingly, these results provide little evidence that the increased coliform trends found in this study are associated with the three pathogens for which samples were tested in this study (including the very dangerous pathogen *E. coli* O157:H7).

Table 16. Summary of bacterial source tracking results for Elbow River and major tributaries in 2003. Results for *E. coli*, Fecal coliforms, Enterococcus, *E. coli* O157:H7, *Salmonella*, *Campylobacter*, and the microbial source tracking primers, human and ruminant PCR, are presence (1)/absence (0). NT=not tested.

								Microbial Source Tracking Primers	
Sites	**Sample Date**	***E. coli*, no./100 mL**	***Fecal* Coliforms, no/100 mL**	**Entero-coccus**	***E. coli* O157:H7**	***Salmonella***	***Campylo-bacter***	**Human PCR**	**Ruminant PCR**
Elbow River Mainstem									
Cobble Flats	21-May-03	2	2	NT	0	0	0	0	0
	15-July-03	4	5	0	0	0	0	0	1
	10-Sep-03	2	2	NT	0	0	0	0	0
	2-Dec-03	<1	2	<1	0	0	0	0	0
Above Bragg Creek	21-May-03	39	44	NT	0	0	0	0	0
	15-Jul-03	11	11	0	0	0	0	0	1
	10-Sep-03	20	20	NT	0	0	0	0	1
	2-Dec-03	<1	3	<1	0	0	0	0	0
Highway 22 Bridge	21-May-03	3	4	NT	0	0	0	0	0
	15-Jul-03	9	13	15	0	0	0	0	1
	10-Sep-03	16	16	NT	0	0	0	0	0
	2-Dec-03	<1	<2	<1	0	0	0	0	0
Glencoe GCC	21-May-03	10	10	NT	0	0	0	0	1
	15-Jul-03	27	40	10	0	0	0	0	1
	10-Sep-03	47	50	NT	0	0	0	0	0
	2-Dec-03	<1	6	1	0	0	0	0	0
Twin Bridges	21-May-03	8	10	NT	0	0	0	0	0
	15-Jul-03	16	18	15	0	0	0	0	1
	10-Sep-03	44	50	NT	0	0	0	0	0
	2-Dec-03	<1	6	<2	0	0	0	0	0
Weaselhead Bridge	21-May-03	1	1	NT	0	0	0	0	0
	15-Jul-03	20	32	20	0	0	0	0	0
	10-Sep-03	89	110	NT	0	0	0	0	0
	2-Dec-03	<1	2	0	0	0	0	0	0
Elbow River Tributaries									
Bragg Creek (West Bragg)	21-May-03	24	70	NT	0	0	0	0	0
	15-Jul-03	120	330	15	0	0	0	0	0
	10-Sep-03	550	600	NT	0	0	0	0	1
	2-Dec-03	24	35	2	0	0	0	0	0
Bragg Creek (mouth)	21-May-03	5	5	NT	0	0	0	0	1
	15-Jul-03	120	120	35	0	0	0	0	0
	10-Sep-03	47	52	NT	0	0	0	0	0
	2-Dec-03	2	2	<1	0	0	0	0	0
Pirmez Creek (headwaters)	21-May-03	2	3	NT	0	0	0	0	0
	15-Jul-03	82	96	5	0	0	0	0	0
	10-Sep-03	17	24	NT	0	0	0	0	0
	2-Dec-03	54	54	<2	0	0	0	0	0
Pirmez Creek (mouth)	21-May-03	360	470	NT	0	0	0	0	1
	15-Jul-03	79	80	45	0	0	0	0	1
	10-Sep-03	200	200	NT	0	0	0	0	0
	2-Dec-03	730	5100	16	0	0	0	0	0
Millburn Creek (RR 40)	21-May-03	1	2	NT	0	0	0	0	0
Millburn Creek (mouth)	21-May-03	36	48	NT	0	0	0	0	1
	15-Jul-03	740	740	225	0	0	0	0	0
	10-Sep-03	260	260	NT	0	0	0	0	0
Springbank Creek (RR 40)	21-May-03	2	2	NT	0	0	0	0	0
	10-Sep-03	30	33	NT	0	1	0	0	1
Springbank Creek (mouth)	21-May-03	11	11	NT	0	0	0	0	0
	15-Jul-03	20	42	30	0	0	0	0	0
	10-Sep-03	210	210	NT	0	0	0	0	1
	2-Dec-03	<1	<2	2	0	0	0	0	0
Lott Creek (Tsuu T'ina boundary)	21-May-03	3	3	NT	0	0	0	0	0
	15-Jul-03	58	58	0	0	0	0	0	0
	2-Dec-03	3	3	<1	0	0	0	0	0
Lott Creek (mouth)	21-May-03	2	2	NT	0	0	0	0	0
	15-Jul-03	11	22	5	0	0	0	0	0
	10-Sep-03	6	6	NT	0	0	0	0	0
	2-Dec-03	7	15	6	0	0	0	0	0
Raw Human Sewage	10-Jan-03	NT	NT	NT	NT	NT	NT	1	1

Table 16. Summary of bacterial source tracking results for Elbow River and major tributaries in 2003. Results for *E. coli*, Fecal coliforms, Enterococcus, *E. coli* O157:H7, *Salmonella*, *Campylobacter*, and the microbial source tracking primers, human and ruminant PCR, are presence (1)/absence (0). NT=not tested.

								Microbial Source Tracking Primers	
Sites	Sample Date	*E. coli*, no./100 mL	*Fecal Coliforms*, no/100 mL	Entero-coccus	*E. coli* O157:H7	*Salmonella*	*Campylo-bacter*	Human PCR	Ruminant PCR
Elbow River Mainstem									
Cobble Flats	21-May-03	2	2	NT	0	0	0	0	0
	15-July-03	4	5	0	0	0	0	0	1
	10-Sep-03	2	2	NT	0	0	0	0	0
	2-Dec-03	<1	2	<1	0	0	0	0	0
Above Bragg Creek	21-May-03	39	44	NT	0	0	0	0	0
	15-Jul-03	11	11	0	0	0	0	0	1
	10-Sep-03	20	20	NT	0	0	0	0	1
	2-Dec-03	<1	3	<1	0	0	0	0	0
Highway 22 Bridge	21-May-03	3	4	NT	0	0	0	0	0
	15-Jul-03	9	13	15	0	0	0	0	1
	10-Sep-03	16	16	NT	0	0	0	0	0
	2-Dec-03	<1	<2	<1	0	0	0	0	0
Glencoe GCC	21-May-03	10	10	NT	0	0	0	0	1
	15-Jul-03	27	40	10	0	0	0	0	1
	10-Sep-03	47	50	NT	0	0	0	0	0
	2-Dec-03	<1	6	1	0	0	0	0	0
Twin Bridges	21-May-03	8	10	NT	0	0	0	0	0
	15-Jul-03	16	18	15	0	0	0	0	1
	10-Sep-03	44	50	NT	0	0	0	0	0
	2-Dec-03	<1	6	<2	0	0	0	0	0
Weaselhead Bridge	21-May-03	1	1	NT	0	0	0	0	0
	15-Jul-03	20	32	20	0	0	0	0	0
	10-Sep-03	89	110	NT	0	0	0	0	0
	2-Dec-03	<1	2	0	0	0	0	0	0
Elbow River Tributaries									
Bragg Creek (West Bragg)	21-May-03	24	70	NT	0	0	0	0	0
	15-Jul-03	120	330	15	0	0	0	0	0
	10-Sep-03	550	600	NT	0	0	0	0	1
	2-Dec-03	24	35	2	0	0	0	0	0
Bragg Creek (mouth)	21-May-03	5	5	NT	0	0	0	0	1
	15-Jul-03	120	120	35	0	0	0	0	0
	10-Sep-03	47	52	NT	0	0	0	0	0
	2-Dec-03	2	2	<1	0	0	0	0	0
Pirmez Creek (headwaters)	21-May-03	2	3	NT	0	0	0	0	0
	15-Jul-03	82	96	5	0	0	0	0	0
	10-Sep-03	17	24	NT	0	0	0	0	0
	2-Dec-03	54	54	<2	0	0	0	0	0
Pirmez Creek (mouth)	21-May-03	360	470	NT	0	0	0	0	1
	15-Jul-03	79	80	45	0	0	0	0	1
	10-Sep-03	200	200	NT	0	0	0	0	0
	2-Dec-03	730	5100	16	0	0	0	0	0
Millburn Creek (RR 40)	21-May-03	1	2	NT	0	0	0	0	0
Millburn Creek (mouth)	21-May-03	36	48	NT	0	0	0	0	1
	15-Jul-03	740	740	225	0	0	0	0	0
	10-Sep-03	260	260	NT	0	0	0	0	0
Springbank Creek (RR 40)	21-May-03	2	2	NT	0	0	0	0	0
	10-Sep-03	30	33	NT	0	1	0	0	1
Springbank Creek (mouth)	21-May-03	11	11	NT	0	0	0	0	0
	15-Jul-03	20	42	30	0	0	0	0	0
	10-Sep-03	210	210	NT	0	0	0	0	1
	2-Dec-03	<1	<2	2	0	0	0	0	0
Lott Creek (Tsuu T'ina boundary)	21-May-03	3	3	NT	0	0	0	0	0
	15-Jul-03	58	58	0	0	0	0	0	0
	2-Dec-03	3	3	<1	0	0	0	0	0
Lott Creek (mouth)	21-May-03	2	2	NT	0	0	0	0	0
	15-Jul-03	11	22	5	0	0	0	0	0
	10-Sep-03	6	6	NT	0	0	0	0	0
	2-Dec-03	7	15	6	0	0	0	0	0
Raw Human Sewage	10-Jan-03	NT	NT	NT	NT	NT	NT	1	1

Since cattle can be important sources for the protozoan parasites *Giardia* and *Cryptosporidium* in Alberta (Heitman et al., 2002), future studies should determine the distribution of these pathogens in the Elbow River basin.

Since no trend in fecal coliform counts was found at the Glencoe GCC, downstream from Pirmez, Millburn, and Springbank Creek, there is little evidence that activities on those tributaries could account for the increase in fecal coliforms at Twin Bridges. However, only four years of fecal coliform sampling were available at the Elbow River at the Glencoe GCC, and there was insufficient fecal coliform data for most tributaries to assess trends in this variable. As discussed previously, it is not possible to determine the relative importance of various potential sources of coliforms that could account for this trend. Since human markers were not found at any site in the bacterial source-tracking project, it seems unlikely that septic leachate or leaking wastewater collection systems could account for the increasing coliform trends.

Summary of Water Quality by Reach

Water quality results from this study (1999 to 2003) for the upper Elbow River are summarized by reach in Table 17. Elbow River tributaries summarized by corresponding reach are shown in Table 18.

Table 17. Summary of water quality, mass flux, temporal trends, and bacterial source tracking for Elbow River mainstem reaches.

Variables[a]	Headwaters to Bragg Creek	Bragg Creek to Hwy 22 Bridge	Hwy 22 Bridge to Twin Bridges	Twin Bridges to Weaselhead Bridge
Temperature	5.8-8.3 °C	5.5-10.0 °C	7.5-12.3 °C	9.1-10.4 °C
Dissolved Oxygen	9.4-10.8 mg/L	9.6-11.3 mg/L	9.3-10.3 mg/L	9.4-10.9 mg/L
pH	8.1-8.3	8.0-8.3	8.0-8.3	8.2-8.3
Conductivity	289-365 µS/cm	293-389 µS/cm	324-404 µS/cm	325-407 µS/cm
Total Organic Carbon	0.5-1.0 mg/L; max 5.5 mg/L	0.8-1.0 mg/L; max 7.1 mg/L	1.1-1.3 mg/L; max 8.6 mg/L	1.0-1.5 mg/L; max 7.0 mg/L
Phosphorus	TP: 0.001-0.003 mg/L; max 0.099 mg/L TDP: 0.001-0.003 mg/L; max 0.062 mg/L	TP: 0.001-0.005 mg/L; max 0.387 mg/L TDP: 0.001-0.002 mg/L; max 0.025 mg/L	TP: 0.002-0.008 mg/L; max 0.505 mg/L TDP: 0.001-0.002 mg/L; max 0.054 mg/L	TP: 0.004-0.012 mg/L; max 0.668 mg/L TDP: 0.001-0.002 mg/L; max 0.044 mg/L
		Net TP mass load of 454 kg in 1999; net decrease of 24 kg in 2000 Net TDP mass decrease of 76 kg in 2000	Net TP mass load of 51 kg in 1999 Net TDP mass not calculated	Net TP mass load of 930 kg in 1999, 255 kg in 2000 Net TDP mass increase of 22 kg in 2000
	No significant trends in TP or TDP concentrations at Cobble Flats; insufficient data to calculate trends at Elbow River above Bragg Creek	Significant decreasing TP trend at Hwy 22 Bridge No significant trend in TDP concentration	No significant TP trend Significant increasing TDP trend at Twin Bridges. No trend at Glencoe	Significant decreasing TP trend at Weaselhead Significant increasing TDP trend at Weaselhead
Nitrogen	NO_3+NO_2: 0.079-0.119 mg/L NH_3: 0.005-0.010 mg/L TKN: 0.08-0.15 mg/L TN: 0.20-0.24 mg/L	NO_3+NO_2: 0.075-0.094 mg/L NH_3: 0.005-0.010 mg/L TKN: 0.07-0.17 mg/L TN: 0.16-0.27 mg/L	NO_3+NO_2: 0.054-0.106 mg/L NH_3: 0.005-0.010 mg/L TKN: 0.11-0.19 mg/L TN: 0.19-0.31 mg/L	NO_3+NO_2: 0.054-0.088 mg/L NH_3: 0.008-0.010 mg/L TKN: 0.09-0.24 mg/L TN: 0.16-0.36 mg/L
		Net NO_3+NO_2 mass decrease of 338 kg in 1999, 1836 kg in 2000, and 1823 kg in 2002 Net NH_3 mass load of 38 kg in 1999, 340 kg in 2002 Net TKN mass decrease of 332 kg in 2000, net increase of 17099 kg in 2002 Net TN mass decrease of 781 kg in 1999 and 4564 kg in 2000; net mass load of 14168 kg in 2002	Net NO_3+NO_2 mass decrease of 1399 kg in 2000 Net NH_3 mass load not calculated Net TKN mass decrease of 673 kg in 2000, net increase of 11497 kg in 2002 Net TN mass decrease of 2623 kg in 1999 and 406 kg in 2000; net mass load of 8000 kg in 2002	Net NO_3+NO_2 mass increase of 800 kg in 1999 and 2246 kg in 2002; net decrease of 384 kg in 2000 Net NH_3 mass decrease of 371 kg in 2002 Net TKN mass decrease of 335 kg in 2000, net increase of 17511 kg in 2002 Net TN mass load of 4411 kg in 1999 and 21251 kg in 2002; net mass decrease of 2140 kg in 2000

Summary of Water Quality by Reach

Water quality results from this study (1999 to 2003) for the upper Elbow River are summarized by reach in Table 17. Elbow River tributaries summarized by corresponding reach are shown in Table 18.

Table 17. Summary of water quality, mass flux, temporal trends, and bacterial source tracking for Elbow River mainstem reaches.

Variables[a]	**Headwaters to Bragg Creek**	**Bragg Creek to Hwy 22 Bridge**	**Hwy 22 Bridge to Twin Bridges**	**Twin Bridges to Weaselhead Bridge**
Temperature	5.8-8.3 °C	5.5-10.0 °C	7.5-12.3 °C	9.1-10.4 °C
Dissolved Oxygen	9.4-10.8 mg/L	9.6-11.3 mg/L	9.3-10.3 mg/L	9.4-10.9 mg/L
pH	8.1-8.3	8.0-8.3	8.0-8.3	8.2-8.3
Conductivity	289-365 μS/cm	293-389 μS/cm	324-404 μS/cm	325-407 μS/cm
Total Organic Carbon	0.5-1.0 mg/L; max 5.5 mg/L	0.8-1.0 mg/L; max 7.1 mg/L	1.1-1.3 mg/L; max 8.6 mg/L	1.0-1.5 mg/L; max 7.0 mg/L
Phosphorus	TP: 0.001-0.003 mg/L; max 0.099 mg/L TDP: 0.001-0.003 mg/L; max 0.062 mg/L	TP: 0.001-0.005 mg/L; max 0.387 mg/L TDP: 0.001-0.002 mg/L; max 0.025 mg/L	TP: 0.002-0.008 mg/L; max 0.505 mg/L TDP: 0.001-0.002 mg/L; max 0.054 mg/L	TP: 0.004-0.012 mg/L; max 0.668 mg/L TDP: 0.001-0.002 mg/L; max 0.044 mg/L
		Net TP mass load of 454 kg in 1999; net decrease of 24 kg in 2000 Net TDP mass decrease of 76 kg in 2000	Net TP mass load of 51 kg in 1999 Net TDP mass not calculated	Net TP mass load of 930 kg in 1999, 255 kg in 2000 Net TDP mass increase of 22 kg in 2000
	No significant trends in TP or TDP concentrations at Cobble Flats; insufficient data to calculate trends at Elbow River above Bragg Creek	Significant decreasing TP trend at Hwy 22 Bridge No significant trend in TDP concentration	No significant TP trend Significant increasing TDP trend at Twin Bridges. No trend at Glencoe	Significant decreasing TP trend at Weaselhead Significant increasing TDP trend at Weaselhead
Nitrogen	NO_3+NO_2: 0.079-0.119 mg/L NH_3: 0.005-0.010 mg/L TKN: 0.08-0.15 mg/L TN: 0.20-0.24 mg/L	NO_3+NO_2: 0.075-0.094 mg/L NH_3: 0.005-0.010 mg/L TKN: 0.07-0.17 mg/L TN: 0.16-0.27 mg/L	NO_3+NO_2: 0.054-0.106 mg/L NH_3: 0.005-0.010 mg/L TKN: 0.11-0.19 mg/L TN: 0.19-0.31 mg/L	NO_3+NO_2: 0.054-0.088 mg/L NH_3: 0.008-0.010 mg/L TKN: 0.09-0.24 mg/L TN: 0.16-0.36 mg/L
		Net NO_3+NO_2 mass decrease of 338 kg in 1999, 1836 kg in 2000, and 1823 kg in 2002 Net NH_3 mass load of 38 kg in 1999, 340 kg in 2002 Net TKN mass decrease of 332 kg in 2000; net increase of 17099 kg in 2002 Net TN mass decrease of 781 kg in 1999 and 4564 kg in 2000; net mass load of 14168 kg in 2002	Net NO_3+NO_2 mass decrease of 1399 kg in 2000 Net NH_3 mass load not calculated Net TKN mass decrease of 673 kg in 2000; net increase of 11497 kg in 2002 Net TN mass decrease of 2623 kg in 1999 and 406 kg in 2000; net mass load of 8000 kg in 2002	Net NO_3+NO_2 mass increase of 800 kg in 1999 and 2246 kg in 2002; net decrease of 384 kg in 2000 Net NH_3 mass decrease of 371 kg in 2002 Net TKN mass decrease of 335 kg in 2000; net increase of 17511 kg in 2002 Net TN mass load of 4411 kg in 1999 and 21251 kg in 2002; net mass decrease of 2140 kg in 2000

Variables[a]	**Headwaters to Bragg Creek**	**Bragg Creek to Hwy 22 Bridge**	**Hwy 22 Bridge to Twin Bridges**	**Twin Bridges to Weaselhead Bridge**
Nitrogen	Significant increasing trend in NO_3+NO_2 at Elbow River above Bragg Creek, no trend at Cobble Flats	Significant increasing trend in NO_3+NO_2 concentration	Significant increasing trend in NO_3+NO_2 concentration	Significant increasing trend in NO_3+NO_2 concentration
	Significant decreasing trend in NH_3 at Elbow River above Bragg Creek; insufficient data for Cobble Flats	No significant trend in NH_3 concentration	Significant increasing trend in NH_3 at Twin Bridges; no trend at Glencoe	No significant trend in NH_3 concentration
	No significant trends in TKN or TN concentrations at Elbow River above Bragg Creek; insufficient data for Cobble Flats	No significant trends in TKN or TN concentrations	No significant trends in TKN or TN concentrations	No significant trends in TKN or TN concentrations
Total Suspended Solids	TSS: 0.2-5.7 mg/L; max 1270 mg/L	TSS: 0.2-8.1 mg/L; max 3570 mg/L	TSS: 1-40.7 mg/L; max 3370 mg/L	TSS: 4-34.3 mg/L; max 1100 mg/L
		Net TSS mass load of 43576 tonnes in 2002	Net TSS mass load of 4550 tonnes in 2002	Net TSS mass load of 725 tonnes in 2000. Net TSS mass decrease of 42163 tonnes in 2002
	Significant decreasing TSS trend at Elbow River above Bragg Creek; insufficient data for Cobble Flats	No significant trend in TSS concentration	Significant increasing trend in TSS at Glencoe; no significant trend at Twin Bridges	No significant trend in TSS concentration at Weaselhead; significant increasing trend in turbidity
Coliform Bacteria	Fecal coliforms: 4-8 per 100 mL; max 50 per 100 mL *E coli*: 2-9 per 100 mL; max 91 per 100 mL	Fecal coliforms: 12-17 per 100 mL; max 100 per 100 mL *E coli*: 4-11 per 100 mL; max 109 per 100 mL	Fecal coliforms: 4-15 per 100 mL; max 54 per 100 mL *E coli*: 1-17 per 100 mL; max 275 per 100 mL	Fecal coliforms: 10-18 per 100 mL; max 370 per 100 mL *E coli*: 16-31 per 100 mL; max 744 per 100 mL
	Significant increasing trend in total coliforms at Cobble Flats, insufficient fecal coliform data; No significant trends in total or fecal coliforms at Elbow River above Bragg Creek	No significant trends in total or fecal coliforms	Significant increasing trends in both total and fecal coliforms at Twin Bridges; no significant trend in fecal coliforms at Glencoe. Insufficient total coliform data at Glencoe	Significant increasing trend in total coliforms at Weaselhead; no significant trend in fecal coliforms
Bacterial Source Tracking (2003)	No *E. coli* O157:H7, *Salmonella*, *Campylobacter* or Human PCR detected Ruminant PCR detected on 1 date (July) at Cobble Flats and 2 dates at Elbow River above Bragg Creek (July, Sept)	No *E. coli* O157:H7, *Salmonella*, *Campylobacter* or Human PCR detected Ruminant PCR detected on 1 date (July) at Hwy 22 Bridge	No *E. coli* O157:H7, *Salmonella*, *Campylobacter* or Human PCR detected Ruminant PCR detected on 2 dates (May, July) at Glencoe and 1 date at Twin Bridges (July)	No *E. coli* O157:H7, *Salmonella*, *Campylobacter*, Human PCR detected No ruminant PCR detected

[a] Variable abbreviations: TP (total phosphorus), TDP (total dissolved phosphorus), NO_2+NO_3 (nitrate+nitrite as N), NH_3 (total ammonia as N), TKN (total kjeldahl nitrogen), TN (total nitrogen), TSS (total suspended solids, as nonfilterable residue), *E. coli* (*Escherichia coli*).

Table 18. Summary of water quality, mass flux, temporal trends, and bacterial source tracking for Elbow River tributaries.

Variables[a]	**Little Elbow River, Prairie Creek, McLean Creek**	**Bragg Creek**	**Pirmez Creek, Millburn Creek, Springbank Creek**	**Lott Creek**
Temperature	5.9-11.3 °C	5.5-9.2 °C	4.8-14.7 °C	9.0-9.8 °C
Dissolved Oxygen	8.8-11.3 mg/L	9.0-11.3 mg/L	9.3-11.1 mg/L	7.9-10.3 mg/L
pH	8.0-8.4	7.7-8.2	7.9-8.2	7.5-7.9
Conductivity	273-354 μS/cm	269-350 μS/cm	411-908 μS/cm	450-483 μS/cm
Total Organic Carbon	0.3-7.6 mg/L; max 18.0 mg/L	3.7-4.2 mg/L; max 14.0 mg/L	2.5-5.5 mg/L; max 17.0 mg/L	1.4-1.8 mg/L; max 16.0 mg/L
Phosphorus	TP: 0.001-0.021 mg/L; max 0.106 mg/L TDP: 0.001-0.007 mg/L; max 0.029 mg/L	TP: 0.007-0.011 mg/L; max 0.525 mg/L TDP: 0.002-0.005 mg/L; max 0.047 mg/L	TP: 0.007-0.076 mg/L; max 0.780 mg/L TDP: 0.002-0.030 mg/L; max 0.140 mg/L	TP: 0.011-0.052 mg/L; max 0.104 mg/L TDP: 0.005-0.015 mg/L; max 0.039 mg/L
		TP mass load of 62 kg in 1999, 16 kg in 2000, 309 kg in 2002 TDP mass load 10 kg in 1999, 8 kg in 2000	Combined TP mass load of 85 kg in 1999, 89 kg in 2002 Combined TDP mass load of 45 kg in 1999, 48 kg in 2002	TP mass load 110 kg in 1999, 94 kg in 2000, 38 kg in 2002. TDP mass load of 26 kg in 1999, 34 kg in 2000, 15 kg in 2002
	No significant trends in TP or TDP concentrations	No significant trends in TP or TDP concentrations	No significant trends in TP or TDP concentrations	No significant trend in TP concentration Significant decreasing TDP concentration
Nitrogen	NO_3+NO_2: 0.005-0.131 mg/L NH_3: 0.010 mg/L TKN: n/a TN: n/a	NO_3+NO_2: 0.051-0.085 mg/L NH_3: 0.005-0.010 mg/L TKN: 0.20-0.33 mg/L TN: 0.29-0.40 mg/L	NO_3+NO_2: 0.002-0.447 mg/L NH_3: 0.005-0.020 mg/L TKN: 0.11-0.66 mg/L TN: 0.26-0.71 mg/L	NO_3+NO_2: 0.087-0.115 mg/L NH_3: 0.03-0.155 mg/L TKN: 0.18-0.46 mg/L TN: 0.28-0.57 mg/L
		NO_3+NO_2 mass load of 105 kg in 1999, 88 kg in 2000, 438kg in 2002 NH_3 mass load of 13 kg in 1999, 61 kg in 2002 TKN mass load of 968 kg in 1999, 429 kg in 2000, 2729 kg in 2002 TN mass load of 1075 kg in 1999, 515 kg in 2000, 3179 kg in 2002	NO_3+NO_2 mass load at Pirmez Creek, 995 kg in 1999, 785 kg in 2000, 2544 kg in 2002; Millburn Creek, 2 kg in 2000; Springbank Creek, 7 kg in 2000, 5 kg in 2002 NH_3 mass load at Millburn Creek of 14 kg in 1999, 10 kg in 2002; Springbank Creek, 4 kg in 2000, 1 kg in 2002; Pirmez Creek, 31 kg in 2002 Combined TKN mass load of 785 kg in 2000, 1229 kg in 2002 Combined TN mass load of 3118 kg in 1999, 1536 kg in 2000, 3700 kg in 2002	NO_3+NO_2 mass load of 306 kg in 1999, 231 kg in 2000, 336 kg in 2002 NH_3 mass load of 294 kg in 1999, 223 kg in 2000, 103 kg in 2002 TKN mass load of 1192 kg in 1999, 806 kg in 2000, 710 kg in 2002 TN mass load of 1489 kg in 1999, 1038 kg in 2000, 1054 kg in 2002

Variables[a]	Headwaters to Bragg Creek	Bragg Creek to Hwy 22 Bridge	Hwy 22 Bridge to Twin Bridges	Twin Bridges to Weaselhead Bridge
Nitrogen	Significant increasing trend in NO_2+NO_3 at Elbow River above Bragg Creek; no trend at Cobble Flats	Significant increasing trend in NO_2+NO_3 concentration	Significant increasing trend in NO_2+NO_3 concentration	Significant increasing trend in NO_2+NO_3 concentration
	Significant decreasing trend in NH_3 at Elbow River above Bragg Creek; insufficient data for Cobble Flats	No significant trend in NH_3 concentration	Significant increasing trend in NH_3 at Twin Bridges; no trend at Glencoe	No significant trend in NH_3 concentration
	No significant trends in TKN or TN concentrations at Elbow River above Bragg Creek; insufficient data for Cobble Flats	No significant trends in TKN or TN concentrations	No significant trends in TKN or TN concentrations	No significant trends in TKN or TN concentrations
Total Suspended Solids	TSS: 0.2-5.7 mg/L; max 1270 mg/L	TSS: 0.2-8.1 mg/L; max 3570 mg/L	TSS: 1-40.7 mg/L; max 3370 mg/L	TSS: 4-34.3 mg/L; max 1100 mg/L
		Net TSS mass load of 43576 tonnes in 2002	Net TSS mass load of 4550 tonnes in 2002	Net TSS mass load of 725 tonnes in 2000. Net TSS mass decrease of 42163 tonnes in 2002
	Significant decreasing TSS trend at Elbow River above Bragg Creek; insufficient data for Cobble Flats	No significant trend in TSS concentration	Significant increasing trend in TSS at Glencoe; no significant trend at Twin Bridges	No significant trend in TSS concentration at Weaselhead; significant increasing trend in turbidity
Coliform Bacteria	Fecal coliforms: 4-8 per 100 mL; max 50 per 100 mL *E. coli*: 2-9 per 100 mL; max 91 per 100 mL	Fecal coliforms: 12-17 per 100 mL; max 100 per 100 mL *E. coli*: 4-11 per 100 mL; max 109 per 100 mL	Fecal coliforms: 4-15 per 100 mL; max 54 per 100 mL *E. coli*: 1-17 per 100 mL; max 275 per 100 mL	Fecal coliforms: 10-18 per 100 mL; max 370 per 100 mL *E. coli*: 16-31 per 100 mL; max 744 per 100 mL
	Significant increasing trend in total coliforms at Cobble Flats, insufficient fecal coliform data. No significant trends in total or fecal coliforms at Elbow River above Bragg Creek	No significant trends in total or fecal coliforms	Significant increasing trends in both total and fecal coliforms at Twin Bridges, no significant trend in fecal coliforms at Glencoe. Insufficient total coliform data at Glencoe	Significant increasing trend in total coliforms at Weaselhead; no significant trend in fecal coliforms
Bacterial Source Tracking (2003)	No *E. coli* O157:H7, *Salmonella*, *Campylobacter* or Human PCR detected Ruminant PCR detected on 1 date (July) at Cobble Flats and 2 dates at Elbow River above Bragg Creek (July, Sept)	No *E. coli* O157:H7, *Salmonella*, *Campylobacter* or Human PCR detected Ruminant PCR detected on 1 date (July) at Hwy 22 Bridge	No *E. coli* O157:H7, *Salmonella*, *Campylobacter* or Human PCR detected Ruminant PCR detected on 2 dates (May, July) at Glencoe and 1 date at Twin Bridges (July)	No *E. coli* O157:H7, *Salmonella*, *Campylobacter*, Human PCR detected No ruminant PCR detected

[a] Variable abbreviations: TP (total phosphorus), TDP (total dissolved phosphorus), NO_2+NO_3 (nitrate+nitrite as N), NH_3 (total ammonia as N), TKN (total kjeldahl nitrogen), TN (total nitrogen), TSS (total suspended solids, as nonfilterable residue), *E. coli* (*Escherichia coli*)

Table 18. Summary of water quality, mass flux, temporal trends, and bacterial source tracking for Elbow River tributaries.

Variables[a]	**Little Elbow River, Prairie Creek, McLean Creek**	**Bragg Creek**	**Pirmez Creek, Millburn Creek, Springbank Creek**	**Lott Creek**
Temperature	5.9-11.3 °C	5.5-9.2 °C	4.8-14.7 °C	9.0-9.8 °C
Dissolved Oxygen	8.8-11.3 mg/L	9.0-11.3 mg/L	9.3-11.1 mg/L	7.9-10.3 mg/L
pH	8.0-8.4	7.7-8.2	7.9-8.2	7.5-7.9
Conductivity	273-354 µS/cm	269-350 µS/cm	411-908 µS/cm	450-483 µS/cm
Total Organic Carbon	0.3-7.6 mg/L, max 18.0 mg/L	3.7-4.2 mg/L, max 14.0 mg/L	2.5-5.5 mg/L, max 17.0 mg/L	1.4-1.8 mg/L, max 16.0 mg/L
Phosphorus	TP: 0.001-0.021 mg/L, max 0.106 mg/L TDP: 0.001-0.007 mg/L, max 0.029 mg/L	TP: 0.007-0.011 mg/L, max 0.525 mg/L TDP: 0.002-0.005 mg/L, max 0.047 mg/L	TP: 0.007-0.076 mg/L, max 0.780 mg/L TDP: 0.002-0.030 mg/L, max 0.140 mg/L	TP: 0.011-0.052 mg/L, max 0.104 mg/L TDP: 0.005-0.015 mg/L, max 0.039 mg/L
		TP mass load of 62 kg in 1999, 16 kg in 2000, 309 kg in 2002 TDP mass load 10 kg in 1999, 8 kg in 2000	Combined TP mass load of 85 kg in 1999, 89 kg in 2002 Combined TDP mass load of 45 kg in 1999, 48 kg in 2002	TP mass load 110 kg in 1999, 94 kg in 2000, 38 kg in 2002 TDP mass load of 26 kg in 1999, 34 kg in 2000, 15 kg in 2002
	No significant trends in TP or TDP concentrations	No significant trends in TP or TDP concentrations	No significant trends in TP or TDP concentrations	No significant trend in TP concentration Significant decreasing TDP concentration
Nitrogen	NO_3+NO_2: 0.005-0.131 mg/L NH_3: 0.010 mg/L TKN: n/a TN: n/a	NO_3+NO_2: 0.051-0.085 mg/L NH_3: 0.005-0.010 mg/L TKN: 0.20-0.33 mg/L TN: 0.29-0.40 mg/L	NO_3+NO_2: 0.002-0.447 mg/L NH_3: 0.005-0.020 mg/L TKN: 0.11-0.66 mg/L TN: 0.26-0.71 mg/L	NO_3+NO_2: 0.087-0.115 mg/L NH_3: 0.03-0.155 mg/L TKN: 0.18-0.46 mg/L TN: 0.28-0.57 mg/L
		NO_3+NO_2 mass load of 105 kg in 1999, 88 kg in 2000, 438kg in 2002 NH_3 mass load of 13 kg in 1999, 61 kg in 2002 TKN mass load of 968 kg in 1999, 429 kg in 2000, 2729 kg in 2002 TN mass load of 1075 kg in 1999, 515 kg in 2000, 3179 kg in 2002	NO_3+NO_2 mass load at Pirmez Creek: 995 kg in 1999, 785 kg in 2000, 2544 kg in 2002; Millburn Creek: 2 kg in 2000; Springbank Creek: 7 kg in 2000, 5 kg in 2002 NH_3 mass load at Millburn Creek of 14 kg in 1999, 10 kg in 2002; Springbank Creek: 4 kg in 2000, 1 kg in 2002; Pirmez Creek: 31 kg in 2002 Combined TKN mass load of 785 kg in 2000, 1229 kg in 2002 Combined TN mass load of 3118 kg in 1999, 1536 kg in 2000, 3700 kg in 2002	NO_3+NO_2 mass load of 306 kg in 1999, 231 kg in 2000, 336 kg in 2002 NH_3 mass load of 294 kg in 1999, 223 kg in 2000, 103 kg in 2002 TKN mass load of 1192 kg in 1999, 806 kg in 2000, 710 kg in 2002 TN mass load of 1489 kg in 1999, 1038 kg in 2000, 1054 kg in 2002

Variables[a]	Little Elbow River, Prairie Creek, McLean Creek	Bragg Creek	Pirmez Creek, Millburn Creek, Springbank Creek	Lott Creek
Nitrogen	Significant increasing trend in NO_3+NO_2 at Little Elbow; no trend at McLean Creek	Significant increasing trend in NO_3+NO_2 concentration	Insufficient data to test for NO_3+NO_2 trend	No significant trend in NO_3+NO_2 concentration
	Significant decreasing trend in NH_3 at McLean Creek; no trend at Little Elbow	No significant trend in NH_3 concentration	Insufficient data to test for NH_3 trend	No significant trend in NH_3 concentration
	Insufficient data to test for TKN or TN trend	Significant decreasing trend in TKN; no significant trend in TN concentration	Insufficient data to test for TKN or TN trend	No significant trends in TKN or TN concentrations
Total Suspended Solids	TSS: 0.2-3.5 mg/L; max 42.5 mg/L	TSS: 0.2-5.9 mg/L; max 87.6 mg/L	TSS: 0.2-5.3 mg/L; max 321 mg/L	TSS: 0.2-4.6 mg/L; max 10 mg/L
		TSS mass load 196 tonnes in 2002	Combined TSS mass load 26 tonnes in 2002	TSS mass load 6 tonnes in 2000, 13 tonnes in 2002
	No significant trends in TSS concentrations	No significant trends in TSS concentrations	No significant trends in TSS concentrations	No significant trends in TSS concentrations
Coliform Bacteria	Fecal coliforms: n/a *E. coli*: 2-46 per 100 mL; max 411 per 100 mL	Fecal coliforms: 48-86 per 100 mL; max 430 per 100 mL *E. coli*: 20-86 per 100 mL; max 1732 per 100 mL	Fecal coliforms: 16-590 per 100 mL; max 4100 per 100 mL *E. coli*: 13-360 per 100 mL; max 3200 per 100 mL	Fecal coliforms: 2-15 per 100 mL; max 160 per 100 mL *E. coli*: 3-10 per 100 mL; max 131 per 100 mL
	Significant increasing trend in total coliforms at both Little Elbow and McLean Creek; insufficient data to test for fecal coliforms	No significant trends in total or fecal coliforms	Insufficient data to test for total or fecal coliforms	Significant increasing trend in total coliforms; no trend in fecal coliforms
Bacterial Source Tracking (2003)		No *E. coli* O157:H7, *Salmonella*, *Campylobacter* or Human PCR detected	No *E. coli* O157:H7, *Campylobacter*, or Human PCR detected Only 1 *Salmonella* detected on one date (Sept) at Springbank Creek at RR 40	No *E. coli* O157:H7, *Salmonella*, *Campylobacter*, or Human PCR detected
		Ruminant PCR detected on 1 date (Sept) at West Bragg site, and 1 date (May) near mouth	Ruminant PCR detected on 2 dates (May, July) at Pirmez Creek near the mouth, but not at headwaters. Ruminant PCR detected on 1 date (May) at Millburn Creek near mouth, but not at RR 40 site. Ruminant PCR detected on 1 date at Springbank Creek (Sept) near mouth and RR 40 site	No ruminant PCR detected at either Lott Creek site (Tsuu T'ina boundary, near mouth)

[a] Variable abbreviations: TP (total phosphorus), TDP (total dissolved phosphorus), NO_2+NO_3 (nitrate+nitrite as N), NH_3 (total ammonia as N), TKN (total kjeldahl nitrogen), TN (total nitrogen), TSS (total suspended solids, as nonfilterable residue), *E. coli* (*Escherichia coli*)

Variables[a]	Little Elbow River, Prairie Creek, McLean Creek	Bragg Creek	Pirmez Creek, Millburn Creek, Springbank Creek	Lott Creek
Nitrogen	Significant increasing trend in NO_3+NO_2 at Little Elbow; no trend at McLean Creek	Significant increasing trend in NO_3+NO_2 concentration	Insufficient data to test for NO_3+NO_2 trend	No significant trend in NO_3+NO_2 concentration
	Significant decreasing trend in NH_3 at McLean Creek; no trend at Little Elbow	No significant trend in NH_3 concentration	Insufficient data to test for NH_3 trend	No significant trend in NH_3 concentration
	Insufficient data to test for TKN or TN trend	Significant decreasing trend in TKN; no significant trend in TN concentration	Insufficient data to test for TKN or TN trend	No significant trends in TKN or TN concentrations
Total Suspended Solids	TSS: 0.2-3.5 mg/L; max 42.5 mg/L	TSS: 0.2-5.9 mg/L; max 87.6 mg/L	TSS: 0.2-5.3 mg/L; max 321 mg/L	TSS: 0.2-4.6 mg/L; max 10 mg/L
		TSS mass load 196 tonnes in 2002	Combined TSS mass load 26 tonnes in 2002	TSS mass load 6 tonnes in 2000, 13 tonnes in 2002
	No significant trends in TSS concentrations	No significant trends in TSS concentrations	No significant trends in TSS concentrations	No significant trends in TSS concentrations
Coliform Bacteria	Fecal coliforms: n/a	Fecal coliforms: 48-86 per 100 mL; max 430 per 100 mL	Fecal coliforms: 16-590 per 100 mL; max 4100 per 100 mL	Fecal coliforms: 2-15 per 100 mL; max 160 per 100 mL
	E coli: 2-46 per 100 mL; max 411 per 100 mL	*E coli*: 20-86 per 100 mL; max 1732 per 100 mL	*E coli*: 13-360 per 100 mL; max 3200 per 100 mL	*E coli*: 3-10 per 100 mL; max 131 per 100 mL
	Significant increasing trend in total coliforms at both Little Elbow and McLean Creek; insufficient data to test for fecal coliforms	No significant trends in total or fecal coliforms	Insufficient data to test for total or fecal coliforms	Significant increasing trend in total coliforms; no trend in fecal coliforms
Bacterial Source Tracking (2003)		No *E. coli* O157:H7, *Salmonella*, *Campylobacter* or Human PCR detected	No *E. coli* O157:H7, *Campylobacter*, or Human PCR detected Only 1 *Salmonella* detected on one date (Sept) at Springbank Creek at RR 40	No *E. coli* O157:H7, *Salmonella*, *Campylobacter*, or Human PCR detected
		Ruminant PCR detected on 1 date (Sept) at West Bragg site, and 1 date (May) near mouth	Ruminant PCR detected on 2 dates (May, July) at Pirmez Creek near the mouth, but not at headwaters. Ruminant PCR detected on 1 date (May) at Millburn Creek near mouth, but not at RR 40 site. Ruminant PCR detected on 1 date at Springbank Creek (Sept) near mouth and RR 40 site	No ruminant PCR detected at either Lott Creek site (Tsuu T'ina boundary, near mouth)

[a] Variable abbreviations: TP (total phosphorus), TDP (total dissolved phosphorus), NO_2+NO_3 (nitrate+nitrite as N), NH_3 (total ammonia as N), TKN (total kjeldahl nitrogen), TN (total nitrogen), TSS (total suspended solids, as nonfilterable residue), *E. coli* (*Escherichia coli*).

Conclusions

Phosphorus

1. Sources near Calgary between Twin Bridges and Weaselhead Bridge generally contributed most of the TP mass entering the Elbow River. Small but significant increasing trends in TDP concentrations and total ammonia suggest that sources in this reach are also contributing dissolved nutrients, which will be more biologically-available than TP to stimulate the growth of aquatic plants.
2. Nonpoint sources of phosphorus in this reach cannot be individually assessed using the available data, but could include urban runoff from new and old residential developments, agricultural activities, groundwater, and direct atmospheric deposition.
3. No evidence of trends in tributary concentration that could account for these increasing trends in TDP in the Elbow River was found. However, TP and TDP median concentrations were higher in tributary streams than in the Elbow River, sometimes well above guidelines and high enough in some streams to have the potential to cause nuisance periphyton growth.
4. Lott Creek contributed the largest mass of TP from tributaries to the Elbow River during 1999 and 2000, when flows were low, and Bragg Creek was the greatest TP mass loading from a tributary in 2002. Although concentrations in tributaries were often high, the mass of TP contributed by tributaries to the Elbow River was much lower than the mass contributed by nonpoint sources, because tributary flows were generally low. In contrast, Lott Creek contributed a greater mass of TDP than nonpoint sources to the lower reach of the Elbow River in 2000.

Nitrogen

1. Appreciable mass loading of nitrate+nitrite to the river occurred in 1999 and 2002 between Twin Bridges and Weaselhead from nonpoint sources close to Calgary and loadings from Lott Creek. Nonpoint sources in this reach could include loadings from urban runoff contributed by storm sewers, atmospheric deposition, agriculture, and contributions from groundwater.
2. A significant increasing trend in nitrate+nitrite concentration occurred at every Elbow River site from just upstream of Bragg Creek to the Weaselhead Bridge, and in several headwater tributaries including the near-pristine Little Elbow River. The reason for these increasing trends in nitrate+nitrite along the Elbow River cannot be determined from the available data in this study. However, a similar pattern found in the upper Bow River suggests that this may be a phenomenon that occurs elsewhere in southern Alberta.
3. Tributaries between Highway 22 and the Glencoe GCC were major sources of nitrate+nitrite, in particular Pirmez Creek, which contributed a greater mass of nitrate+nitrite each year than any other tributary. Nitrate concentrations were high enough to have the potential to cause nuisance growth of periphyton in Pirmez Creek in some years. However, nitrate+nitrite measurements at all other sites were well below all other numerical Canadian water quality guidelines for this variable.
4. TN and TKN mass flux generally followed the same pattern as nitrate+nitrite, with a loss of mass along some reaches of the Elbow River during low flow years (1999 and 2000), and some evidence of nonpoint source loading and loading from Lott Creek close to Calgary.

5. Tributaries contributed a greater mass of TKN and TN to the Elbow River than nonpoint sources during low flow years. Although TKN and TN median concentrations were generally highest in Millburn Creek, Lott Creek contributed the greatest mass of TKN in 1999 and 2000, and Bragg Creek was the greatest tributary source of both variables in 2002, when flows were higher.

Total Suspended Solids

1. Sources between Twin Bridges and Weaselhead Bridge contributed the bulk of the suspended sediment to the Elbow River during years of low to average flows. Some possible sources include the re-suspension of bed material, bank erosion (located during an aerial survey), and storm sewers that release urban runoff. TSS loadings from all tributaries were very small each year compared to nonpoint sources along the Elbow River, with only 0.3% of the total mass flux coming from tributaries in 2002.
2. During the high flows in 2002, a large influx of TSS mass occurred between Bragg Creek and Highway 22, more than was contributed by nonpoint sources along any other reach of the Elbow River that year. Bank erosion at various sites and other potential TSS sources in that reach were identified during an aerial survey in November 2002. This large influx of TSS mass probably caused concentrations in 2002 to peak at the Glencoe GCC.
3. The mass flux analysis suggests that the area of greatest deposition of TSS occurred just upstream of Twin Bridges in 2000, but more deposition occurred downstream between Twin Bridges and Sarcee Bridge during the higher flows in 2002. These findings suggest that the spatial pattern of TSS loading and deposition changes considerably from year to year depending on river flows and other factors.

Coliform Bacteria

1. The greatest loading of *E. coli* to the Elbow River occurred each year between the Glencoe GCC and Weaselhead Bridge. *E. coli* counts declined from Highway 22 to the Glencoe GCC in 1999 and 2000, then increased significantly at sites further downstream. *E. coli* counts were generally significantly higher at Twin Bridges and Weaselhead Bridge than at most upstream sites, including the site at the Glencoe GCC. Fecal coliforms have increased significantly over time (1979-2002) at the Twin Bridges site alone.
2. Except for Lott Creek, tributaries had higher *E. coli* and fecal coliform counts than the Elbow River sites in low to average flows (1999 and 2000). Among tributary sites, both *E. coli* and fecal coliforms were consistently lowest in Lott Creek and highest in either Pirmez or Millburn Creek near the mouth. Fecal coliform counts in both Millburn Creek and Pirmez Creek generally exceeded the guidelines for irrigation and contact recreation, indicating that water quality for these uses was impaired in these streams.
3. Since no trend in fecal coliform counts was detected in the Elbow River at the Glencoe GCC, a site downstream from Pirmez, Millburn, and Springbank Creeks, there is no evidence to suggest that activities on those tributaries would account for the increasing trend in fecal coliform counts in the Elbow River further downstream at Twin Bridges. Similarly no evidence was found that human sewage could account for this trend.
4. Between Glencoe GCC and Twin Bridges, runoff from residential developments, agriculture, groundwater, and other nonpoint sources, could contribute to increasing fecal coliform counts in the Elbow River at Twin Bridges. As with other variables in this reach it is not possible to determine the relative importance of various sources of coliforms.

5. Ruminant markers were found on at least one trip at all sampling locations in the Elbow River basin except at sites on Lott Creek, the headwaters of Pirmez Creek, Weaselhead Bridge, and the headwaters of Millburn Creek, which was only flowing on one sampling date. These results confirm that ruminant animals are present upstream from all sampling locations where such markers were found, even in the headwaters of the Elbow River at Cobble Flats. No human markers were found at any sampling site, although this marker was found in a raw sewage sample. This implies that there was little or no movement of bacteria from human sewage to these water bodies during the sampling period.

6. None of the human pathogens, except for *Salmonella*, was found at any site. *Salmonella* was detected at one site on one date. Samples were tested for the following human pathogens: *E. coli* 0157:H7, *Salmonella*, and *Campylobacter*.

Hamlet of Bragg Creek

1. Results of this sampling program did not provide consistent evidence of impacts on water quality in the Elbow River that might be attributed to sources in the Hamlet of Bragg Creek. In 1999 before the spring flood, nonpoint sources contributed 454 kg TP to the Elbow River between the Bragg Creek and Highway 22 Bridge; however there was no increase in TP mass between these sites in 2000. *E. coli* counts increased each year between the Hamlet of Bragg Creek and Highway 22 Bridge, but counts at these sites were only significantly different in 2000.

Recommendations

1. ***Bank Erosion.*** The upper Elbow River is naturally prone to bank erosion. Its banks are readily eroded in various locations during high flows, which occur during years with high runoff from mountain snowmelt. Analysis of water quality trends has detected increased turbidity and TSS levels in recent decades. During the same time period, necessary channel modifications have been made at various locations, to improve bank stability and reduce erosion. However, erosion continues at some of these sites and downstream, with turbidity levels in the Elbow River increasing. This suggests that current approach to bank protection has not proven effective.

   Other approaches to erosion protection should be considered. For example, restrictions on development of the flood plain and the flood fringe have been used elsewhere to protect naturally unstable channels like the upper Elbow River. Development in vulnerable sections of the Elbow River flood plain and flood fringe should be restricted.

2. ***Agricultural Impacts.*** Except for nitrogen and other nonpoint impacts along the mainstem Elbow, this study found little evidence that agricultural activities on tributaries have had a significant impact on water quality in the Elbow River. Indirect agricultural impacts on the Elbow River via groundwater were not assessed in this study, but could be an important pathway. However, impaired water quality for irrigation and contact recreation was found in some tributaries and some of this impairment probably reflects current agricultural practices. The Farmers of the Elbow Watershed (FEW) have implemented a program to improve agricultural practices and reduce water quality impacts in the Elbow basin. Their efforts to improve agricultural practices on tributary streams should be supported and enhanced.

3. ***Urban Runoff.*** Our sampling during low to average flows provided evidence of appreciable TSS, TP, and coliform loadings from sources near Calgary. As with agriculture, the contribution of urban runoff has not been separately quantified. However, since there are few remaining farms downstream from Twin Bridges, the bulk of this loading is probably from urban sources, including various storm sewers that discharge to this reach. The individual contribution of current and future storm sewer systems needs to be carefully assessed, and improved where feasible and cost-effective. The adoption of Best Management Practices by stakeholders within the watershed can also help address this issue and should be encouraged.

4. ***Bacterial Source Tracking and Protozoan Sampling.*** The bacterial source tracking study in 2003 was completed during a relatively dry summer and found no evidence of bacterial DNA from human sources such as septic fields. The sampling should be repeated during a wetter year, when there could be more movement of septic leachate into streams and rivers. The protozoan parasites *Giardia* and *Cryptosporidium* are currently sampled by the City of Calgary at several sites in the Elbow watershed. More intensive sampling throughout the watershed would help to determine the relative contributions of agriculture, wildlife, and urban sources.

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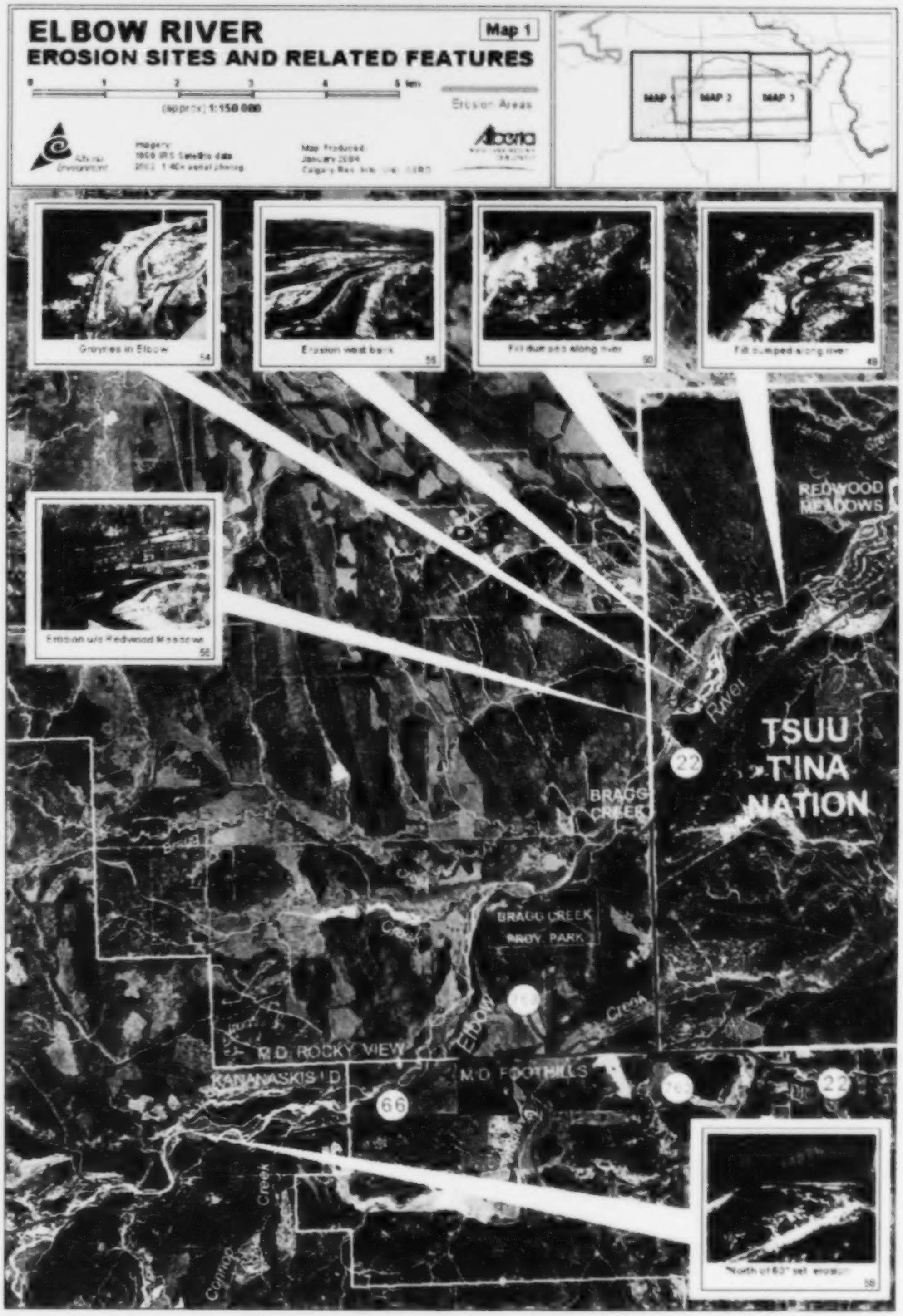
ELBOW RIVER
EROSION SITES AND RELATED FEATURES
Map 1
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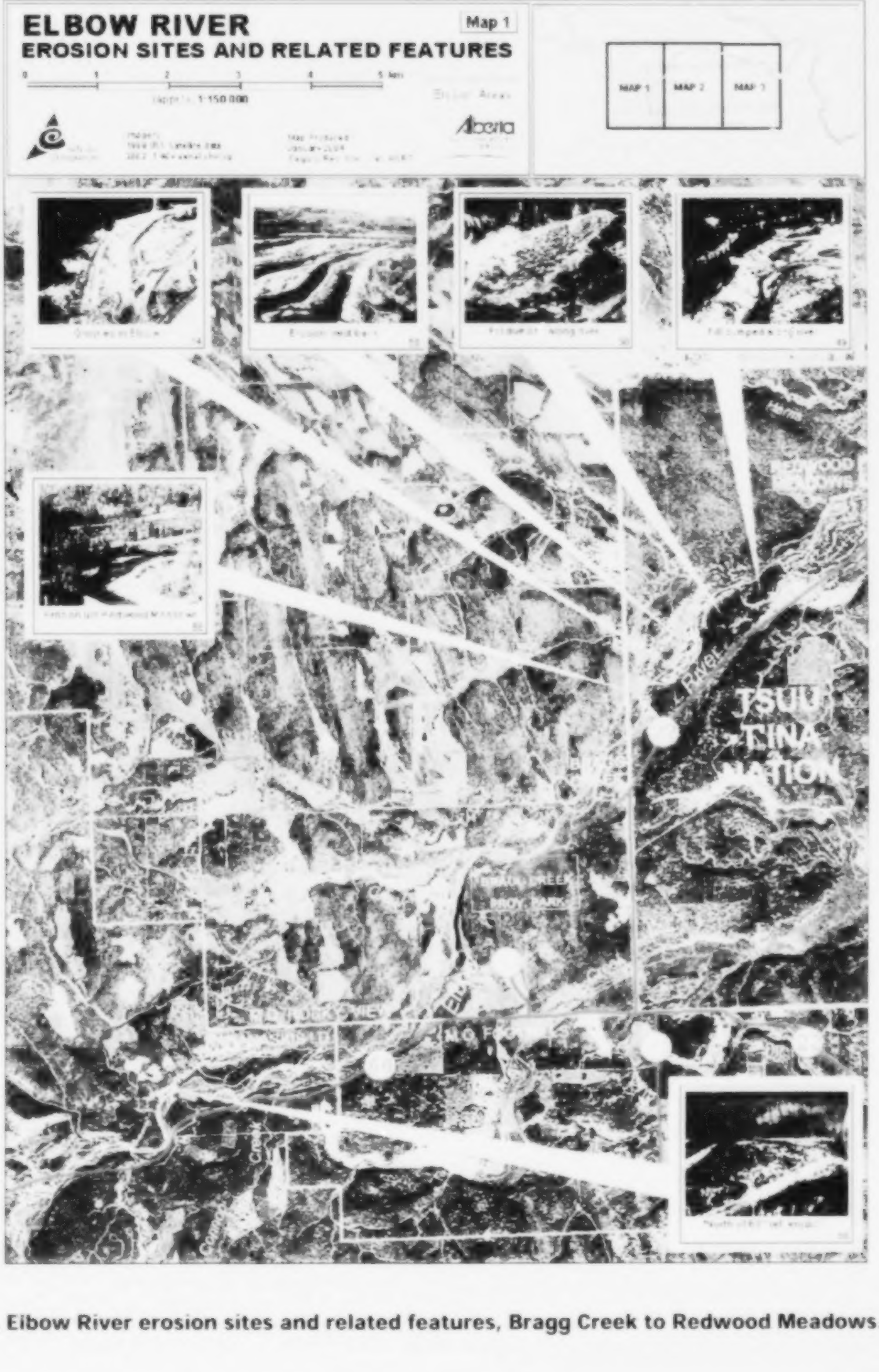
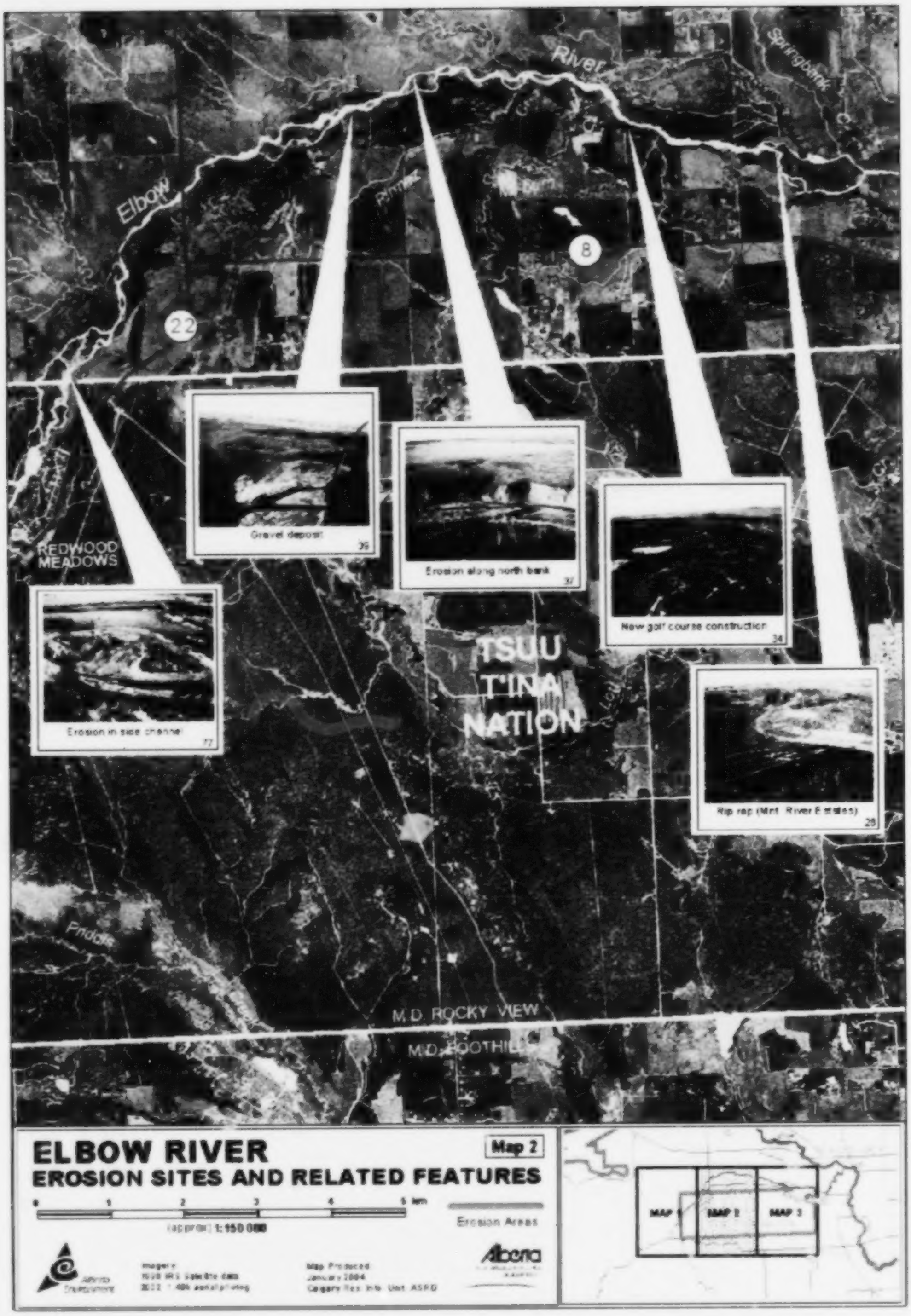
1
2
3
4
5 km
(approx) 1:150 000
Erosion Areas
Imagery:
2002 1:40k aerial photog
Map Produced
January 2004
Alberta
MAP 1
MAP 2
MAP 3
Groynes in Elbow
54
Erosion west bank
55
Fill dumped along river
50
Fill dumped along river
49
Erosion u/s Redwood Meadows
56
"North of 63" set. erosion
38
REDWOOD MEADOWS
River
TSUU T'INA NATION
22
BRAGG CREEK
Bragg
Creek
BRAGG CREEK PROV. PARK
Elbow
Creek
M.D. ROCKY VIEW
KANANASKIS I.D.
M.D. FOOTHILLS
66
22
Creek
Canyon

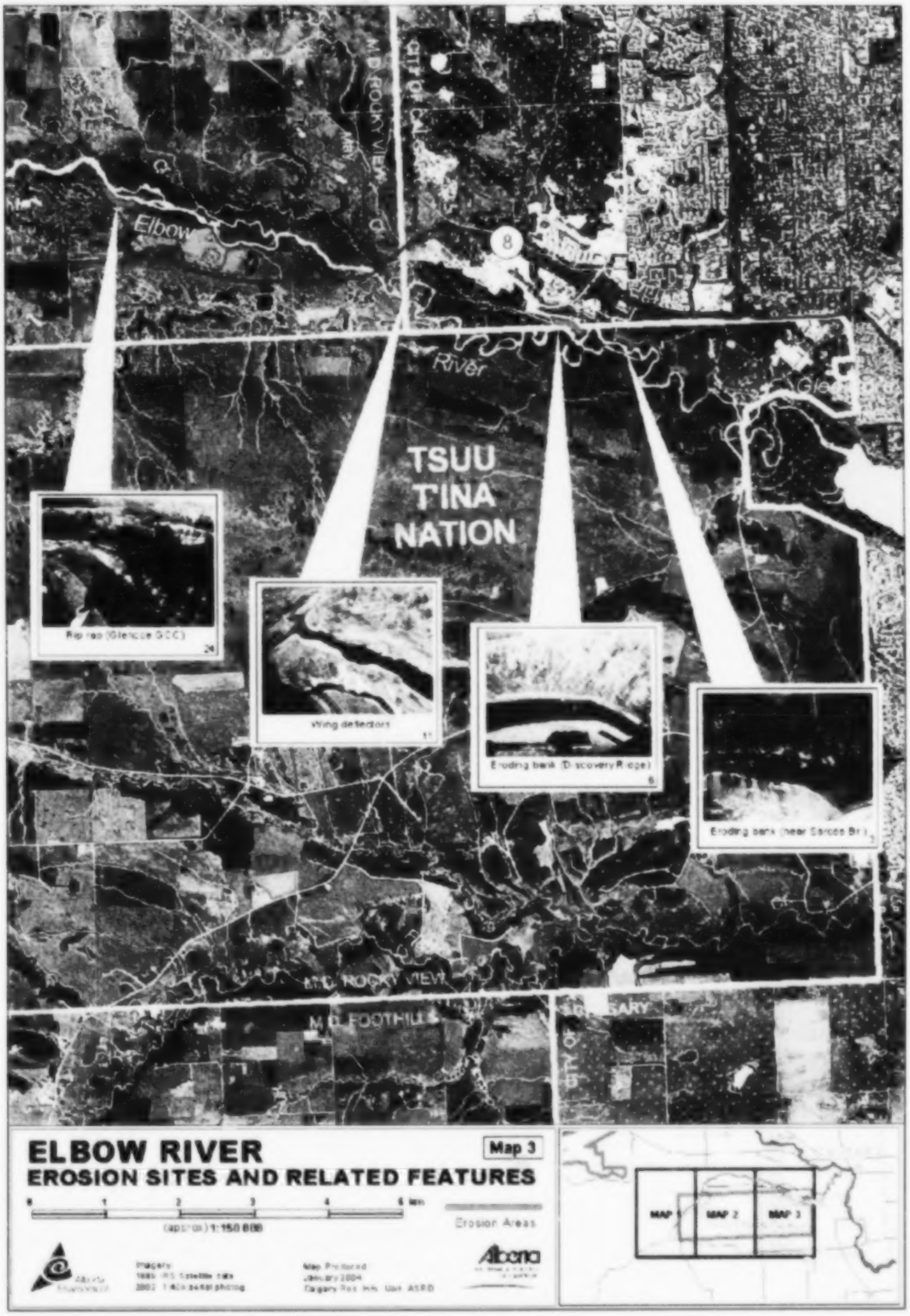
Map 1. Elbow River erosion sites and related features, Bragg Creek to Redwood Meadows.


ELBOW RIVER
EROSION SITES AND RELATED FEATURES
Map 1
0
1
2
3
4
5 km
1:150 000
Alberta
MAP 1
MAP 2
MAP 3
River
TSUU T'INA NATION
REDWOOD MEADOWS

Map 1. Elbow River erosion sites and related features, Bragg Creek to Redwood Meadows.


Elbow
River
Springbank
8
22
REDWOOD MEADOWS
Gravel deposit
36
Erosion along north bank
37
New golf course construction
34
Erosion in side channel
77
Rip rap (Mnt. River Estates)
29
TSUU T'INA NATION
Priddis
M.D. ROCKY VIEW
M.D. FOOTHILLS
ELBOW RIVER
EROSION SITES AND RELATED FEATURES
Map 2
0
1
2
3
4
5 km
(approx) 1:150 000
Erosion Areas
Imagery
Map Produced
January 2004
Calgary Reg. Info. Unit ASRD
MAP 1
MAP 2
MAP 3

Map 2. Elbow River erosion sites and related features, Redwood Meadows to Glencoe GCC.



M.D. ROCKY VIEW
CITY OF CAL
Elbow
River
8
Glenmore
TSUU
T'INA
NATION
Rip rap (Glencoe GCC)
20
Wing deflectors
11
Eroding bank (Discovery Ridge)
6
Eroding bank (near Sarcee Br.)
3
M.D. ROCKY VIEW
M.D. FOOTHILLS
CITY OF CALGARY
ELBOW RIVER
EROSION SITES AND RELATED FEATURES
Map 3
0
1
2
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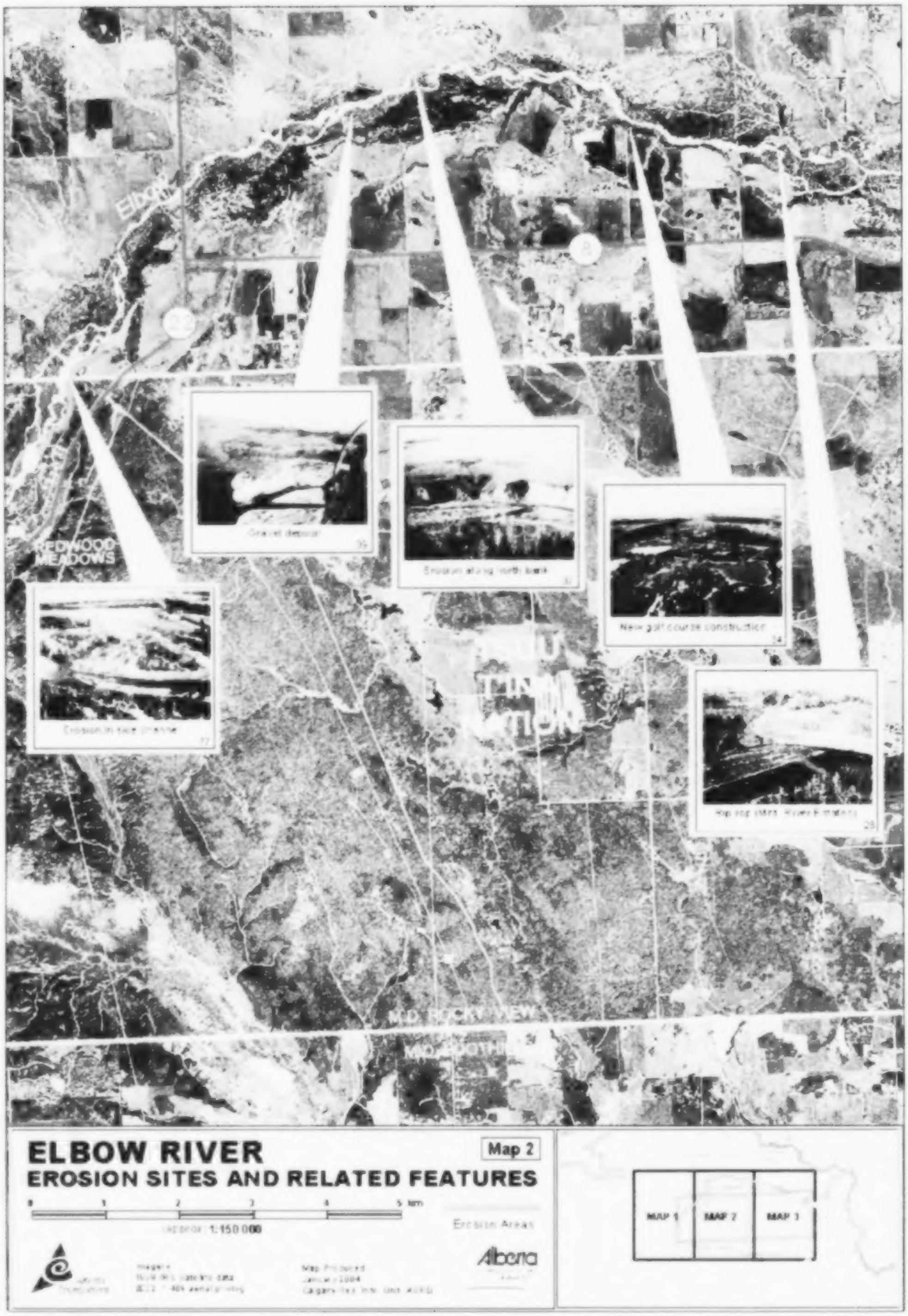
4
5 km
(approx) 1:150 000
Erosion Areas
Imagery
Map Produced
January 2004
Alberta
MAP 1
MAP 2
MAP 3

Map 3. Elbow River erosion sites and related features, Glencoe GCC to Weaselhead.


Elbow
REDWOOD MEADOWS
Gravel deposit
39
Erosion along north bank
Erosion in side channel
New golf course construction
34
Rip rap
28
M.D. ROCKY VIEW
ELBOW RIVER
Map 2
EROSION SITES AND RELATED FEATURES
0
1
2
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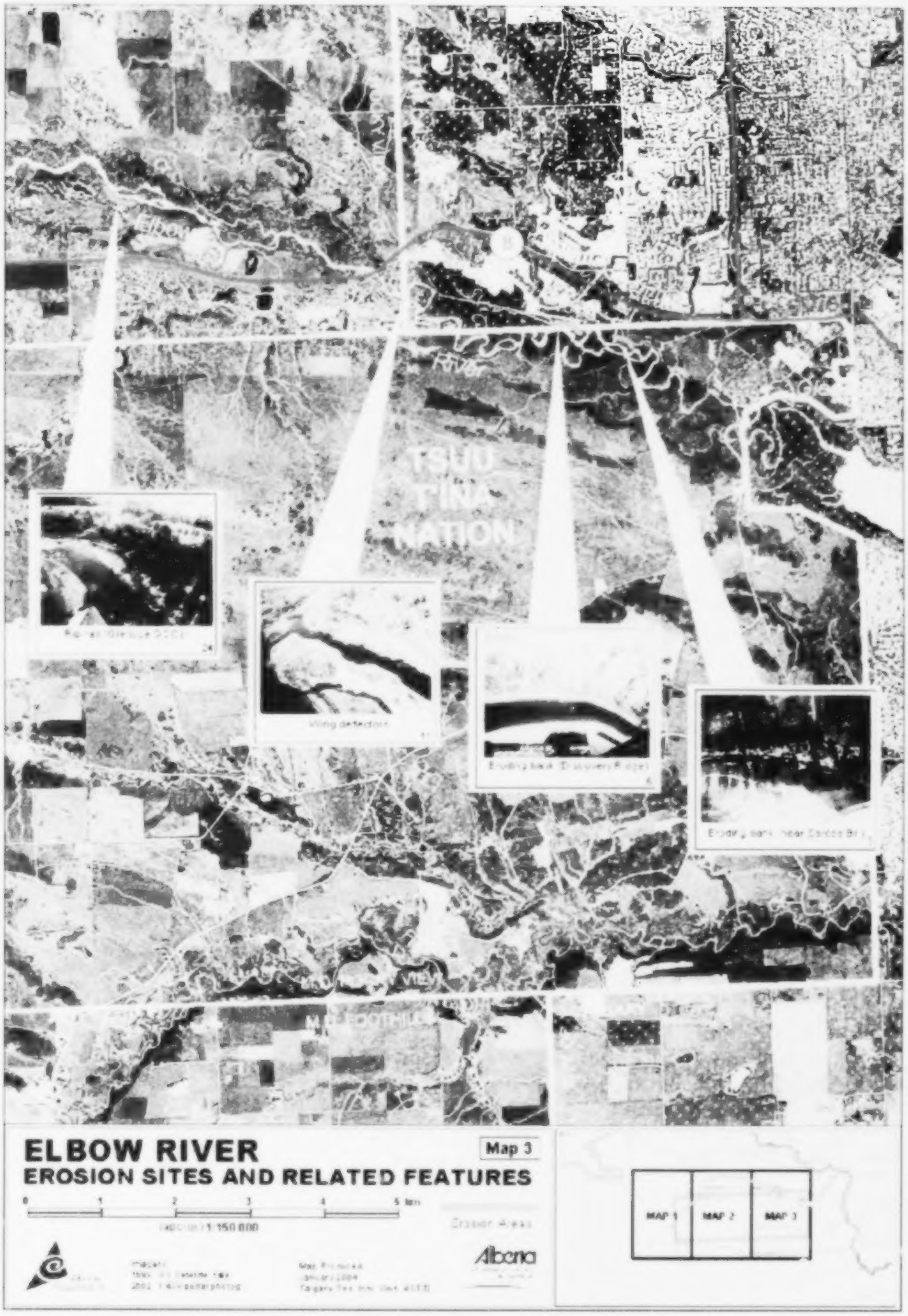
4
5 km
1:150 000
Erosion Areas
Alberta
MAP 1
MAP 2
MAP 3
Map Produced
January 2004

Map 2. Elbow River erosion sites and related features, Redwood Meadows to Glencoe GCC.


Elbow
River
TSUU T'INA NATION
Wing deflection
Eroding bank (Discovery Ridge)
ELBOW RIVER
Map 3
EROSION SITES AND RELATED FEATURES
0
1
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4
5 km
1:150 000
Erosion Areas
Alberta
MAP 1
MAP 2
MAP 3

Map 3. Elbow River erosion sites and related features, Glencoe GCC to Weaselhead.